



How form errors impact on 2D precision assembly?

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Université de Savoie

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Mechanical assemblies:

- stack up of part,
- assemblies with clearances

Theoretical assembly: stack up

Assumptions

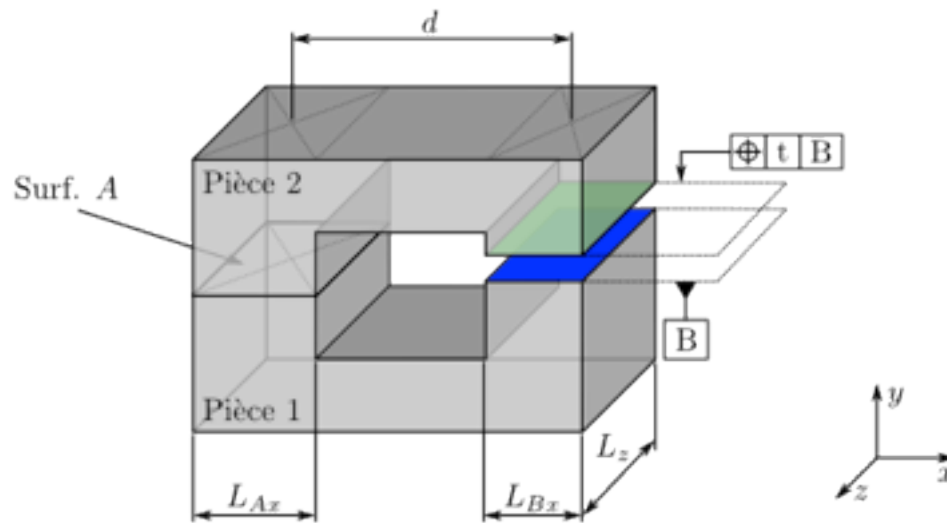
- Rigid parts
- No clearance
- Positioning force

Theoretical assembly: stack up

Assumptions

- Rigid parts
- No clearance
- Positioning force

→ No form deviations



$$L_{Ax} = 40 \text{ mm}$$

$$L_{Bx} = 20 \text{ mm}$$

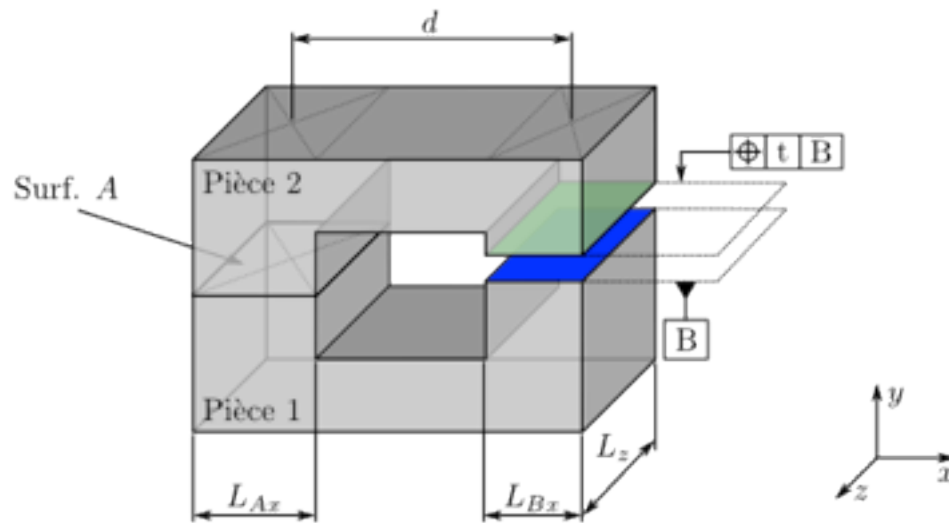
$$L_z = 40 \text{ mm}$$

Theoretical assembly: stack up

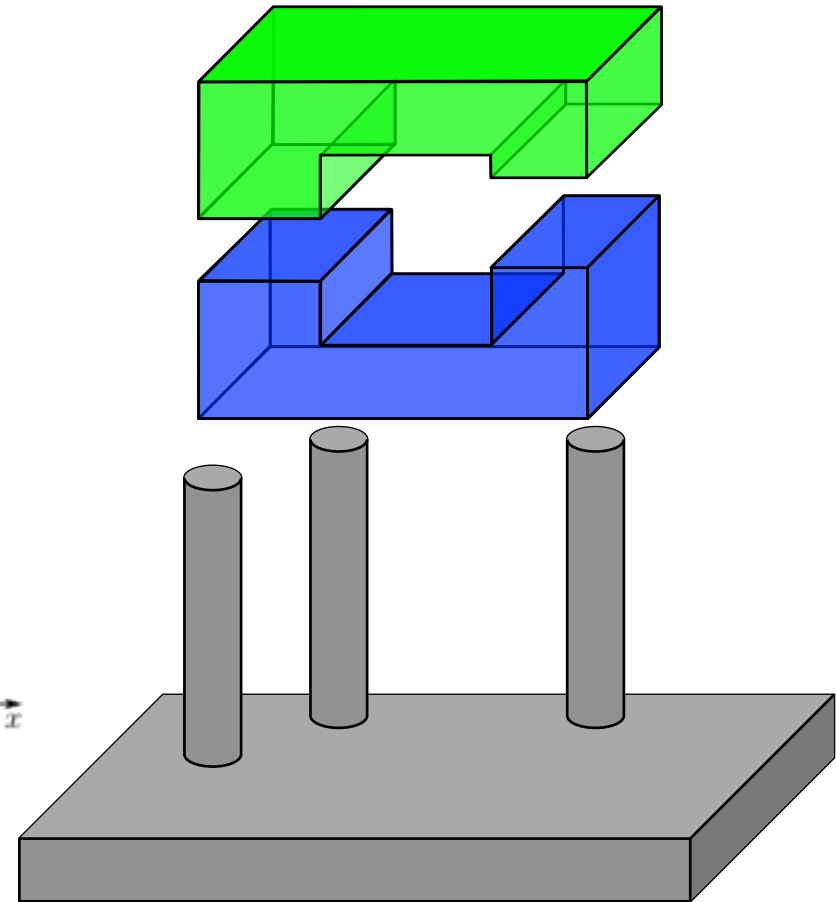
Assumptions

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$$\begin{aligned}L_{Ax} &= 40 \text{ mm} \\L_{Bx} &= 20 \text{ mm} \\L_z &= 40 \text{ mm}\end{aligned}$$

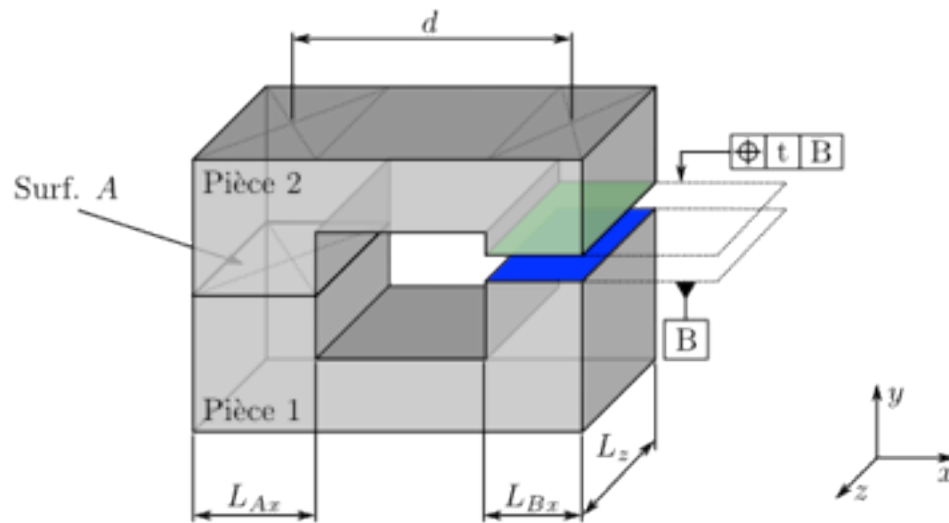


Theoretical assembly: stack up

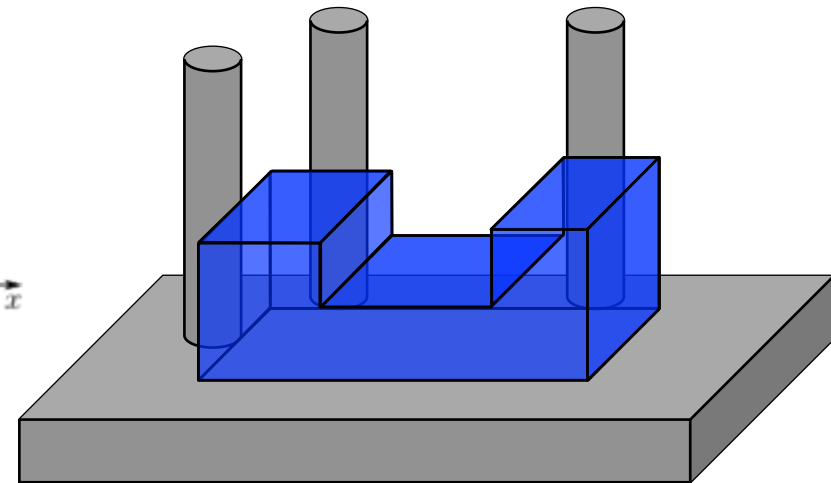
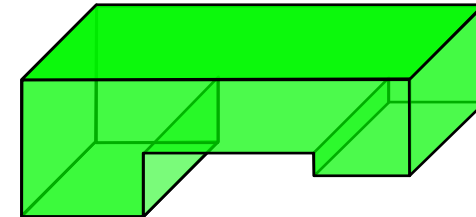
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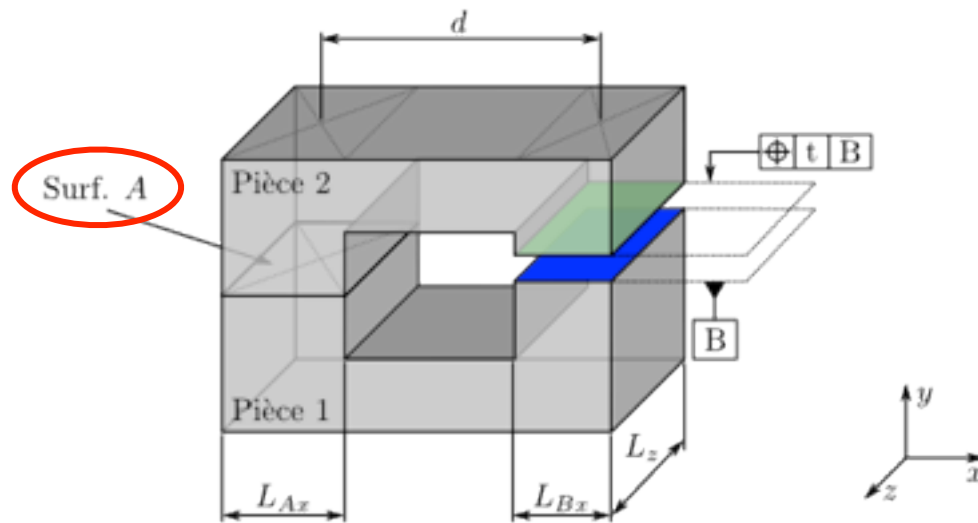


Theoretical assembly: stack up

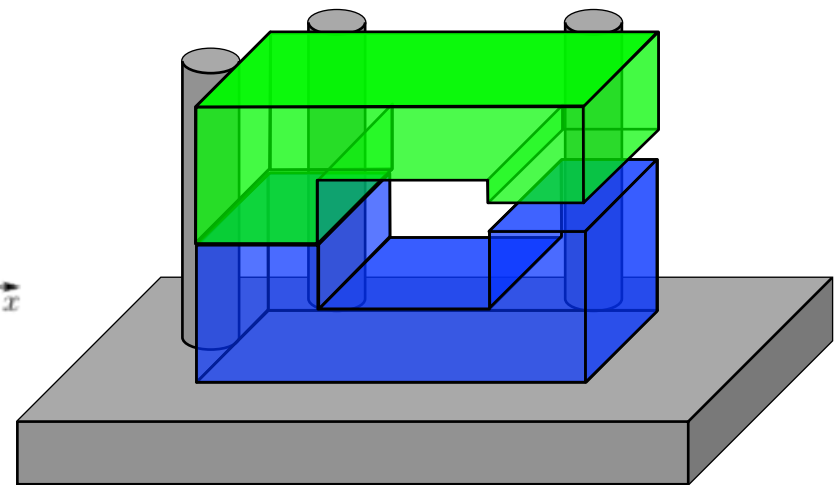
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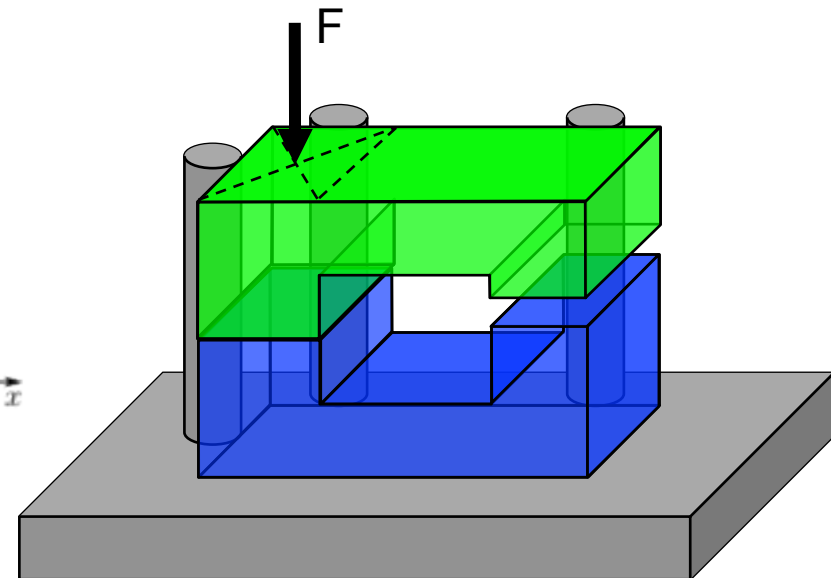
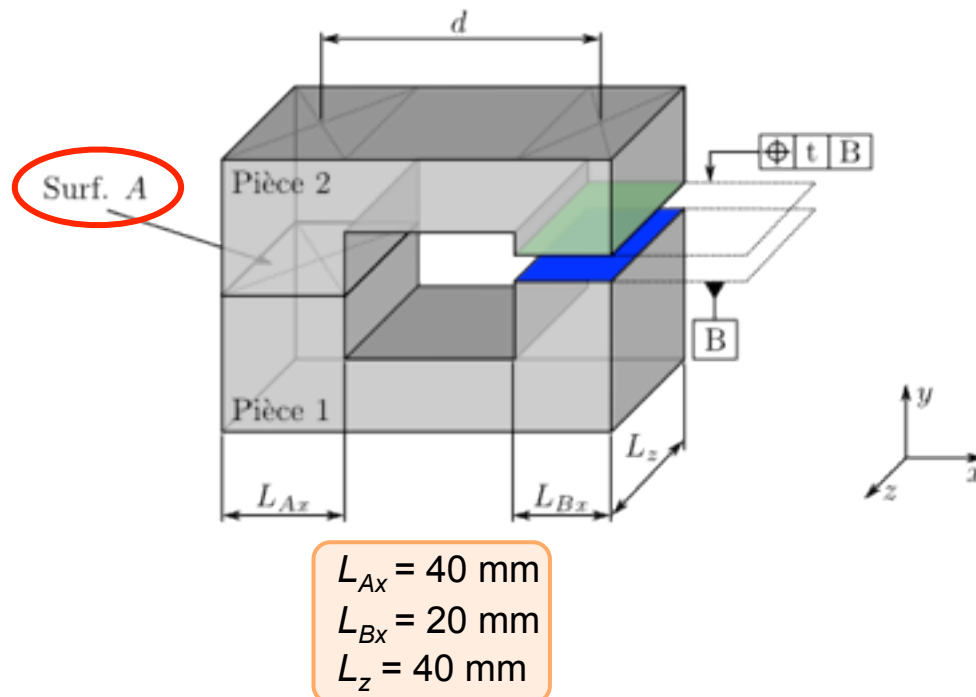


Theoretical assembly: stack up

Assumptions

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→ No form deviations

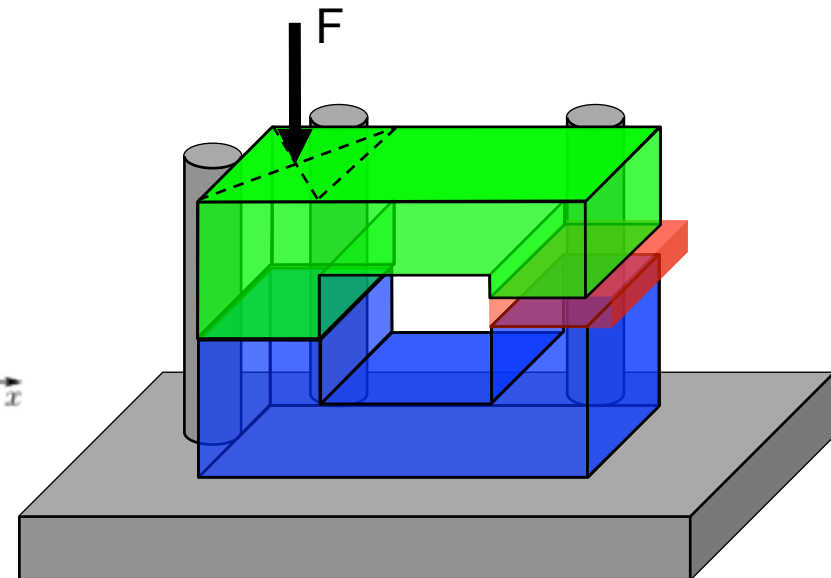
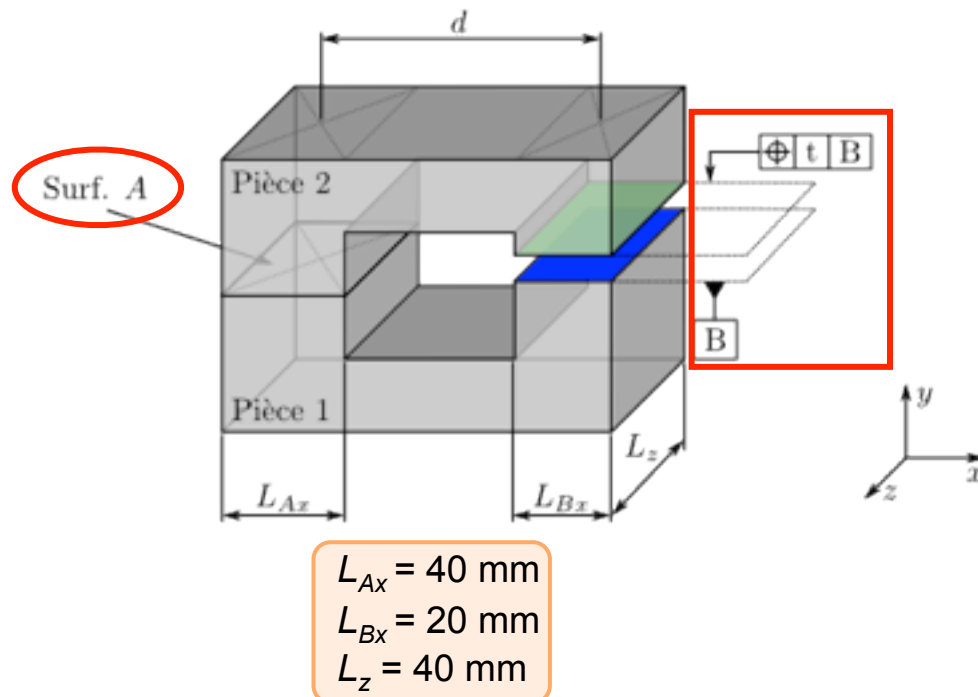


Theoretical assembly: stack up

Assumptions

- Rigid parts
- No clearance
- Positioning force

→ No form deviations



Theoretical assembly: clearance

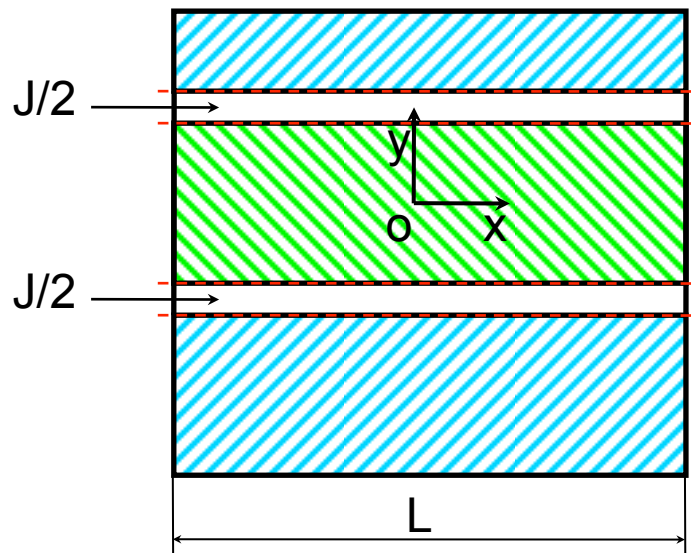
Assumptions

- Rigid parts
- Clearance

Theoretical assembly: clearance

Assumptions

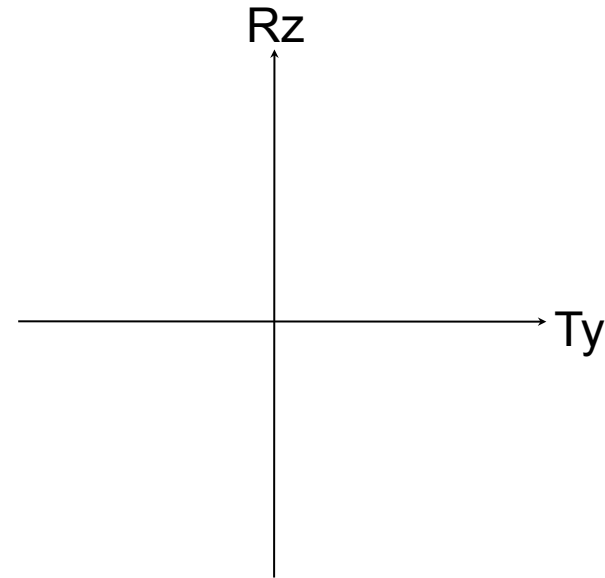
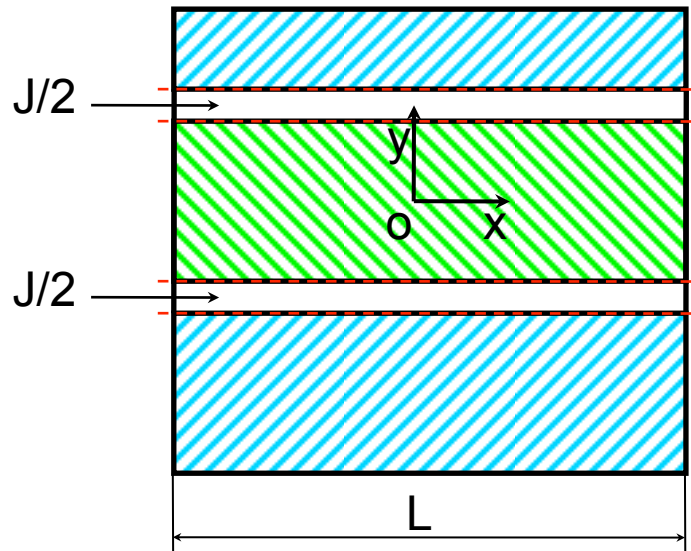
- Rigid parts
- Clearance



Theoretical assembly: clearance

Assumptions

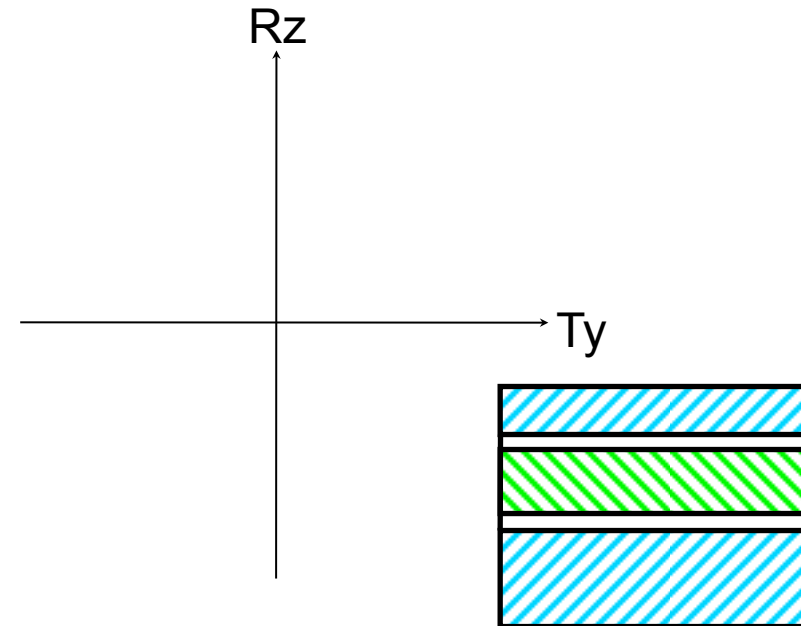
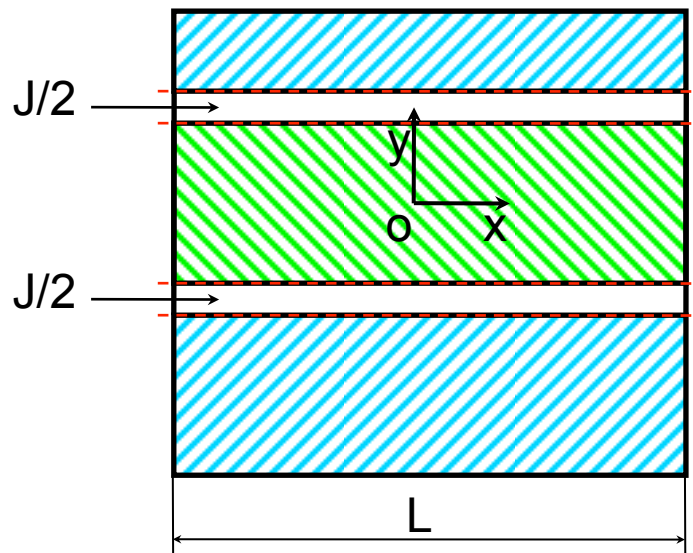
- Rigid parts
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Theoretical assembly: clearance

Assumptions

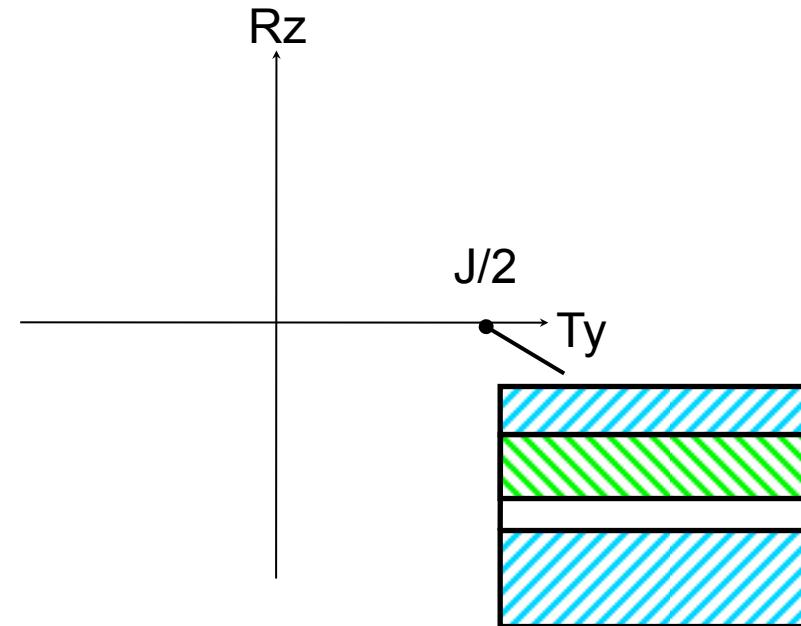
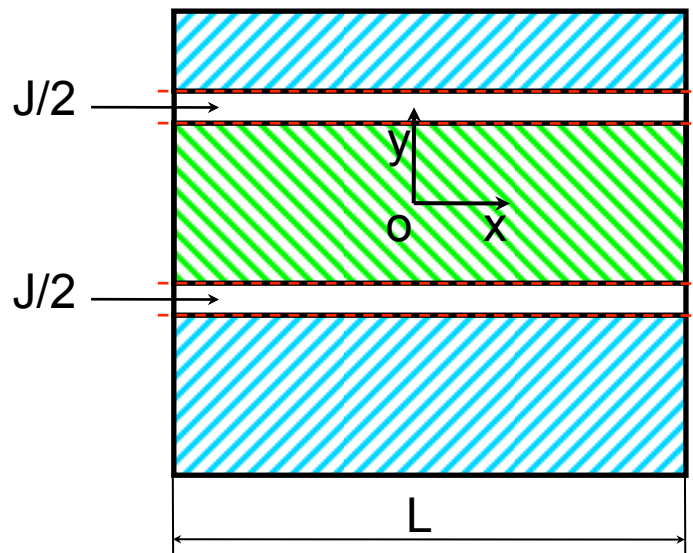
- Rigid parts
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Theoretical assembly: clearance

Assumptions

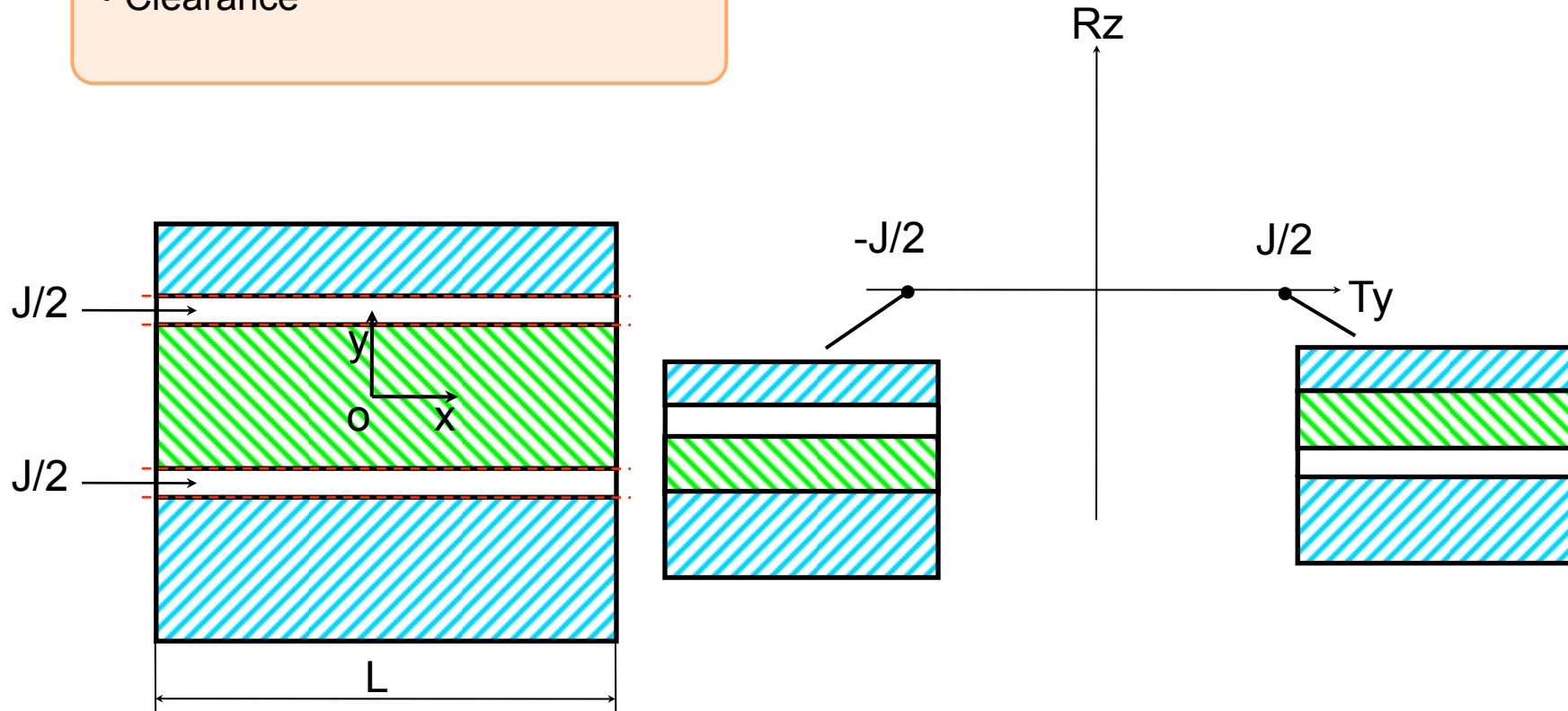
- Rigid parts
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Theoretical assembly: clearance

Assumptions

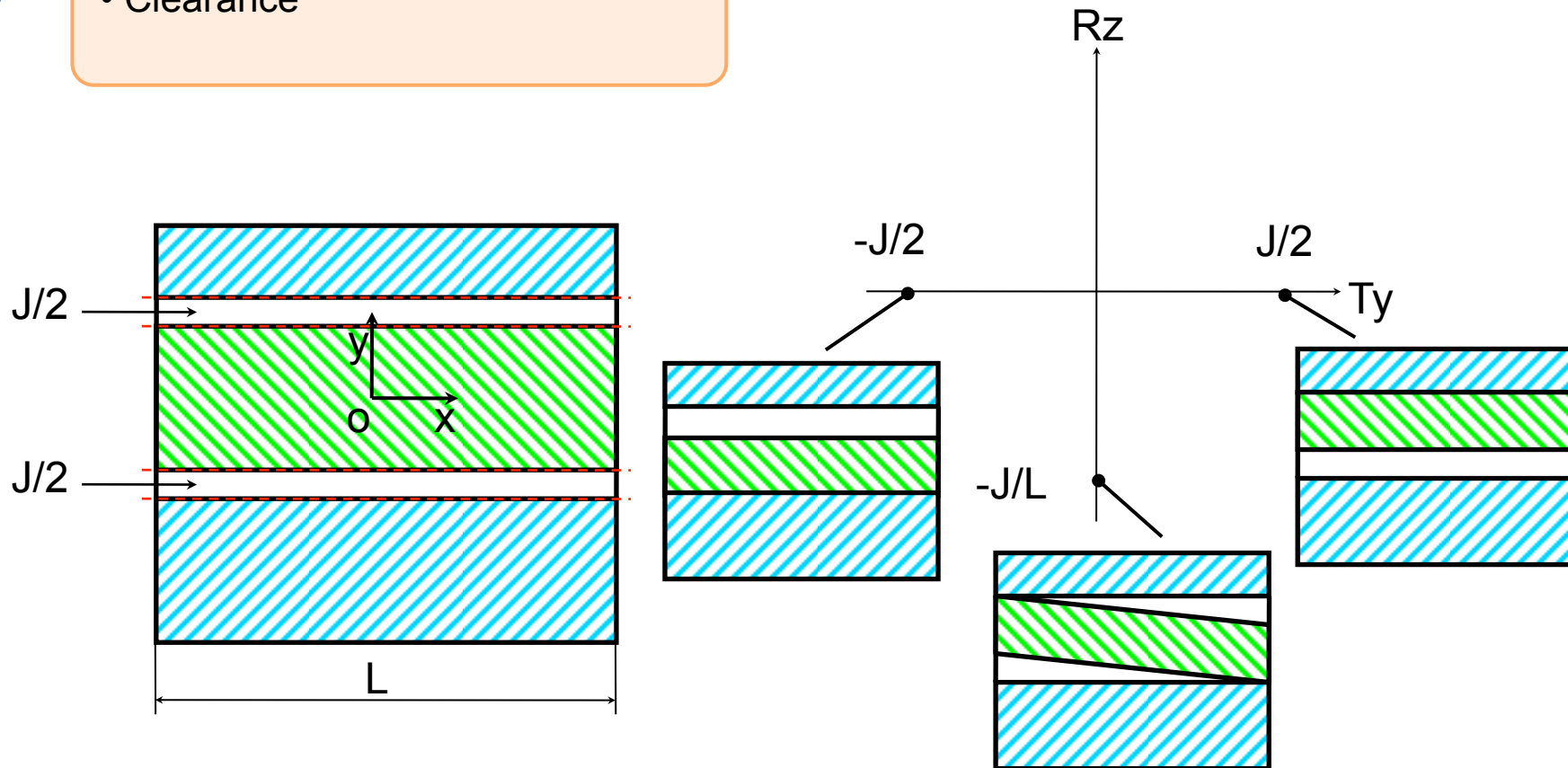
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Theoretical assembly: clearance

Assumptions

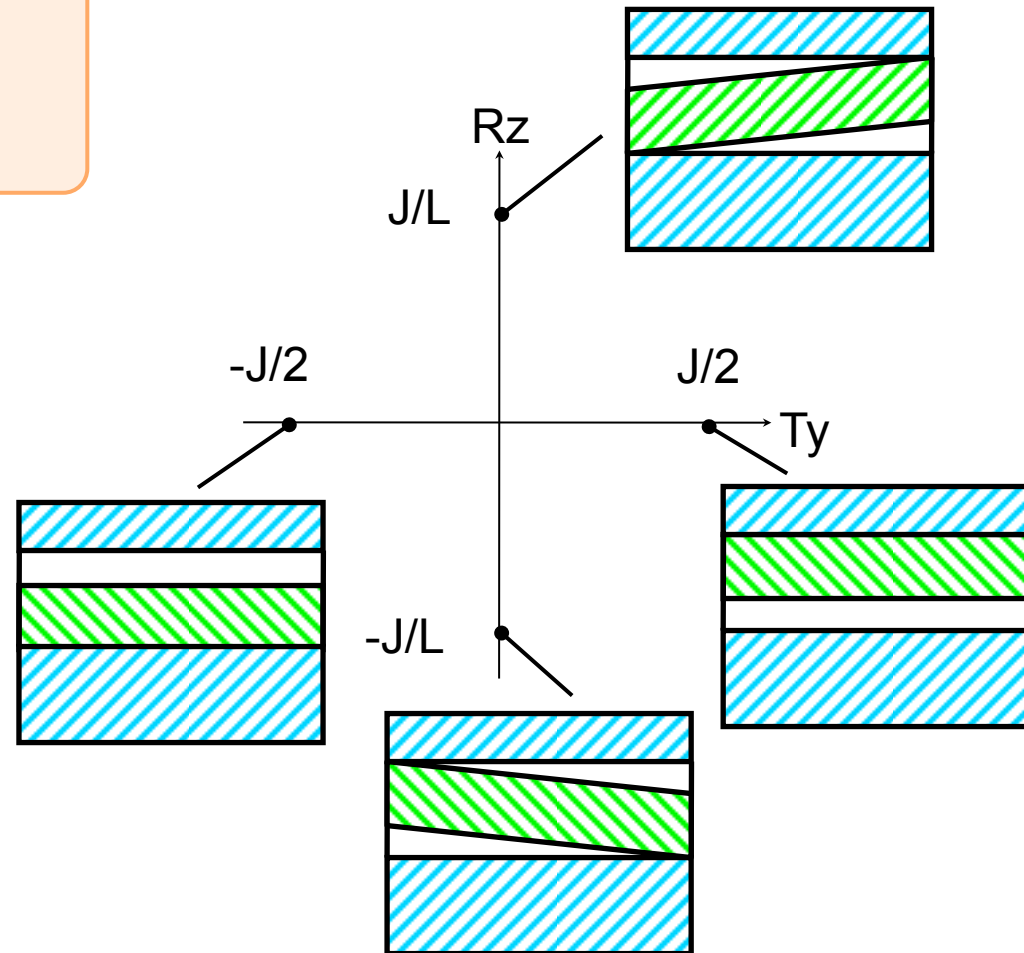
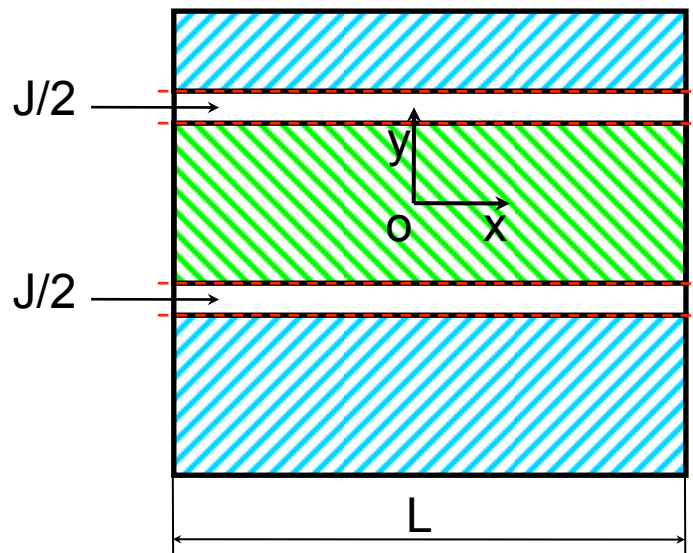
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Theoretical assembly: clearance

Assumptions

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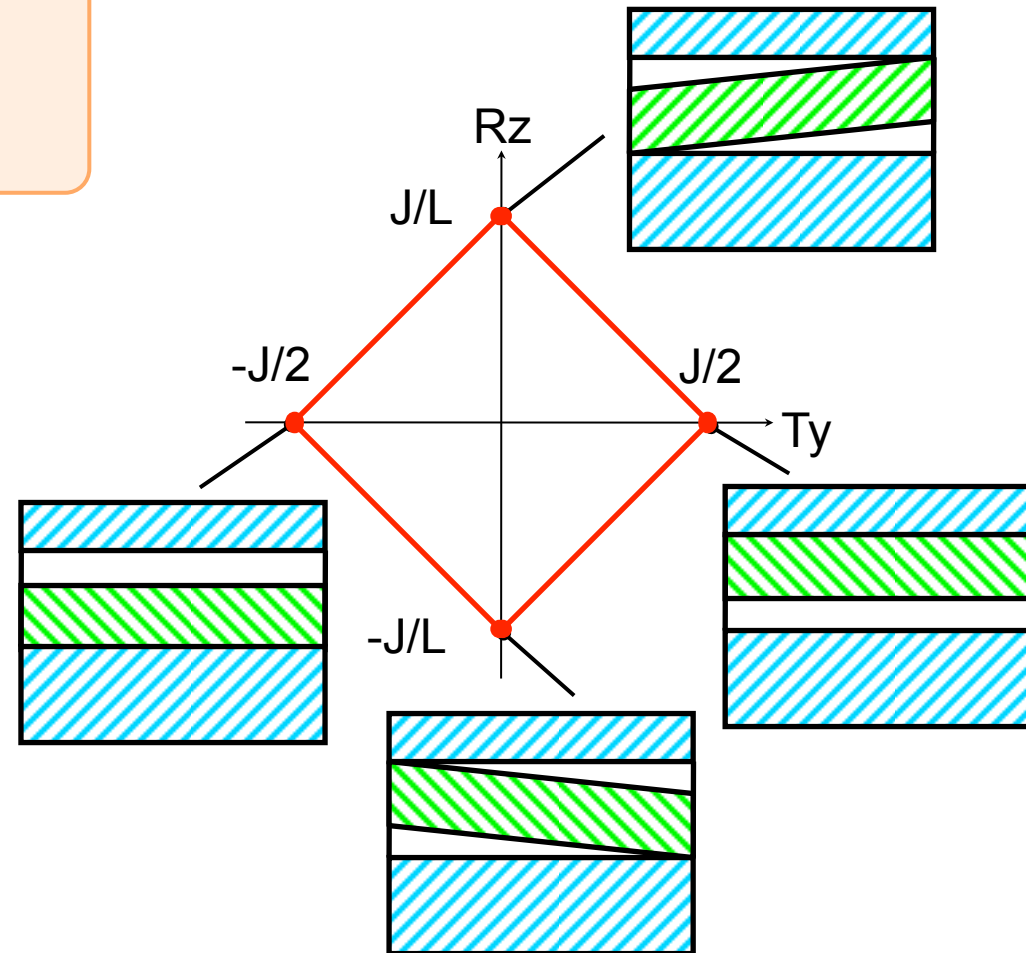
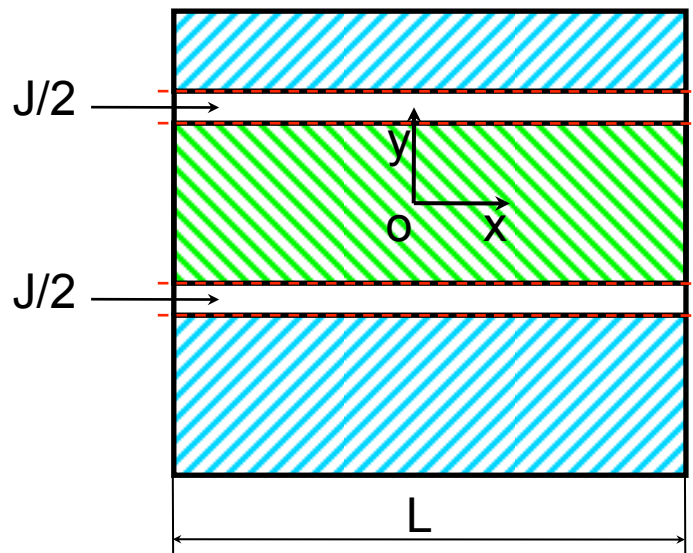


Theoretical assembly: clearance

Assumptions

- Rigid parts
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→ No form deviations



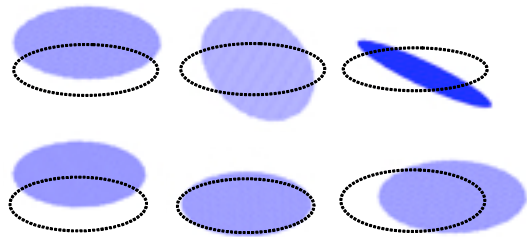


The modal parameterization of form deviations

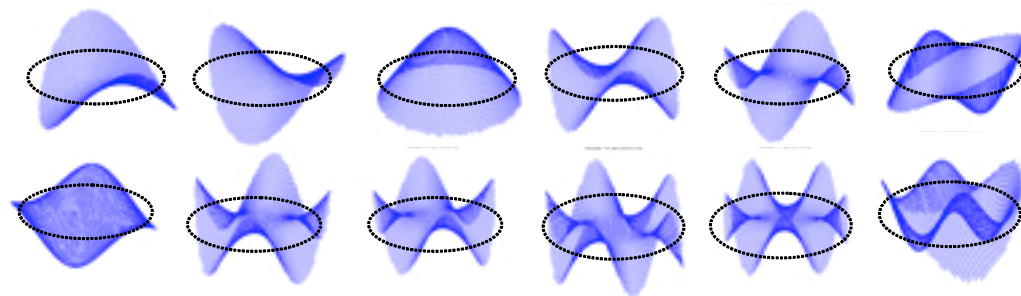
Modal parameterization

- **Creation of a basis of elementary shape deviation:**
 - Based on the nominal geometry (CAD model),
 - Created by the modal vibration behaviour of the model,

Rigid modes



Vibration modes

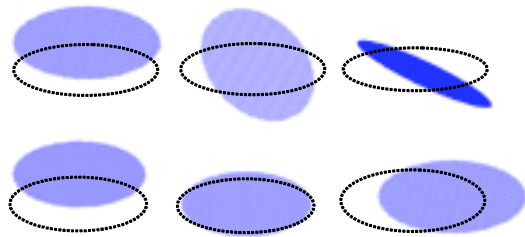


- **Properties of this approach:**
 - Applicable on all kind of geometry (profile, surface, ...),
 - Provides elementary form deviations with growing complexity,

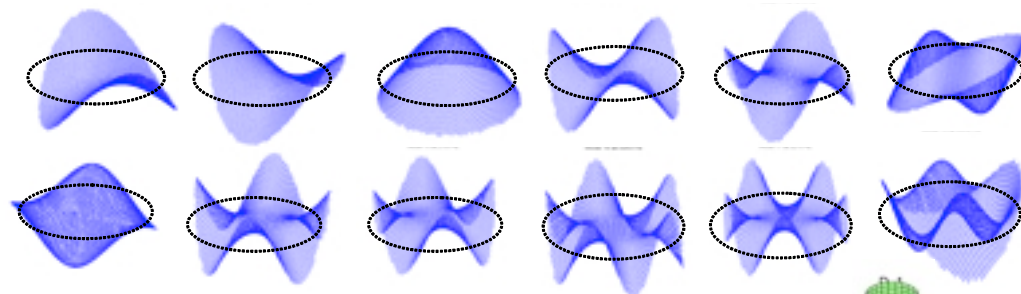
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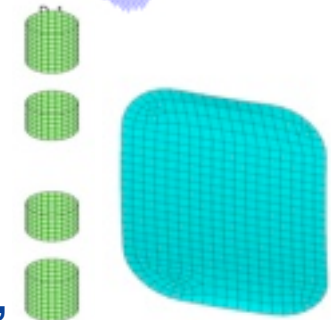
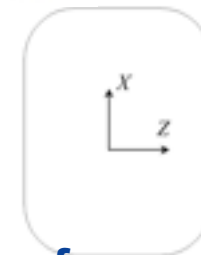
Rigid modes



Vibration modes

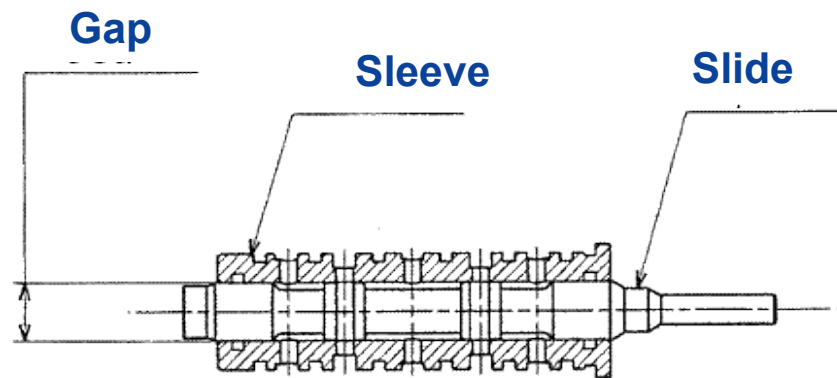


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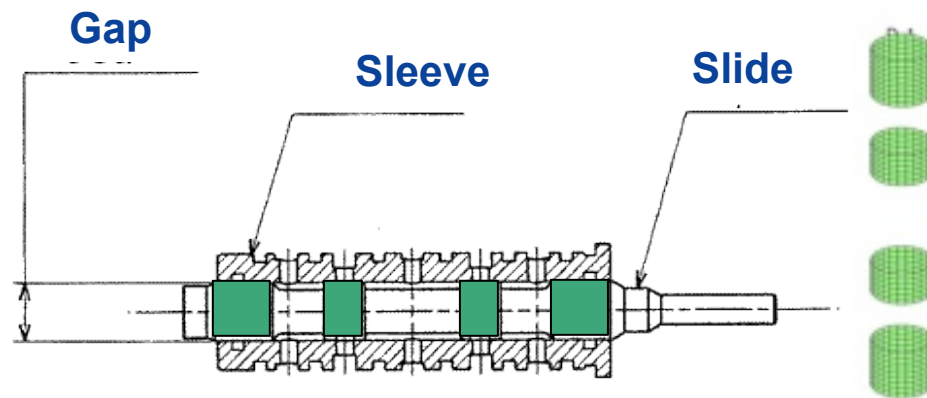
Modal parameterization

- An exhaustive basis of elementary form deviation



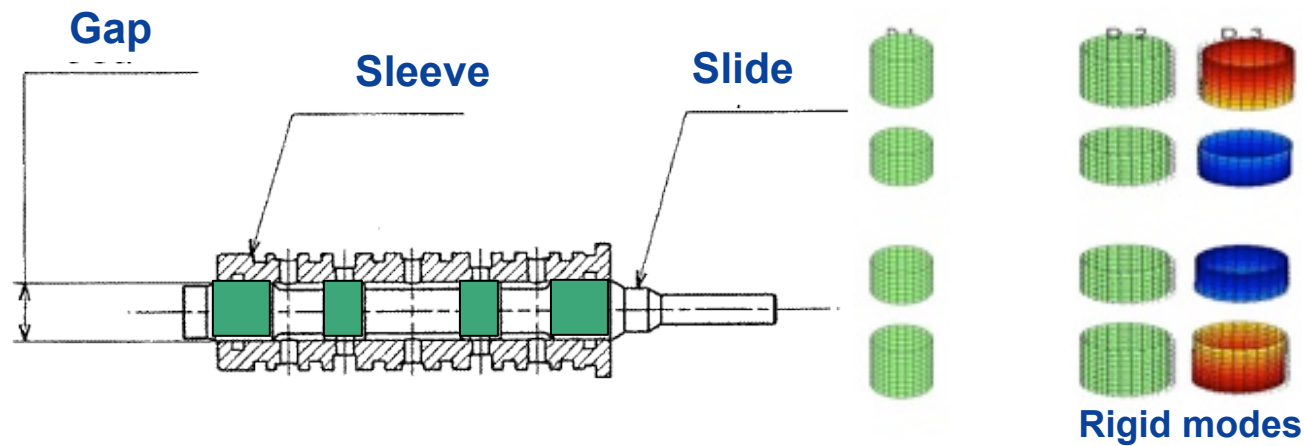
Modal parameterization

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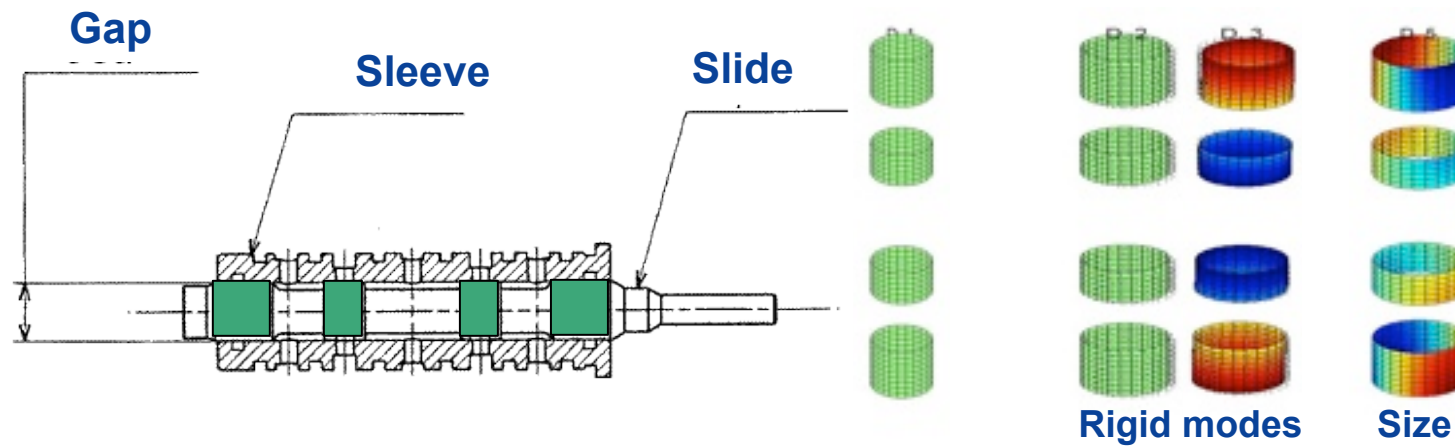
Modal parameterization

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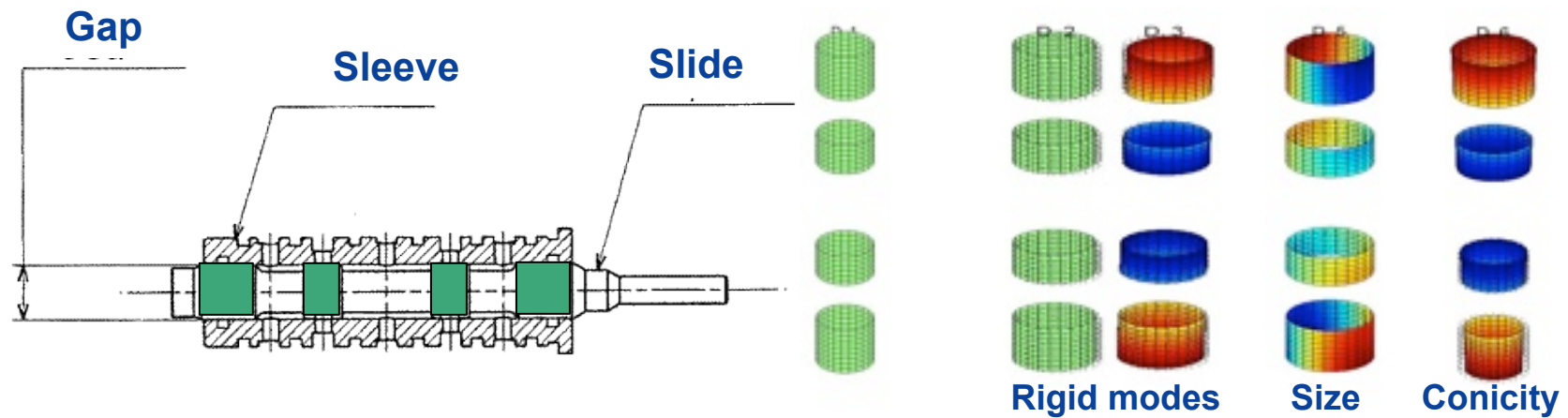
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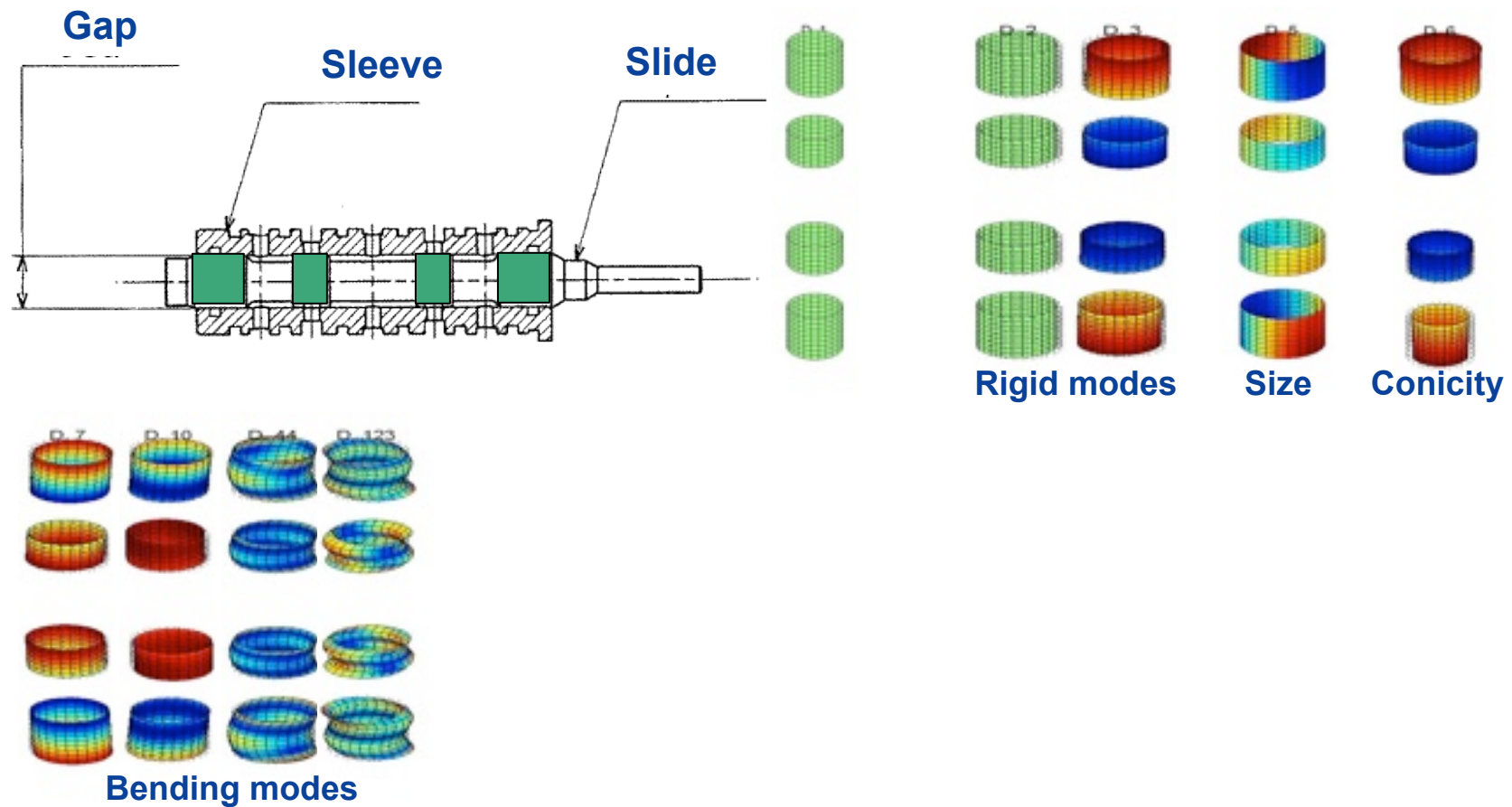
Modal parameterization

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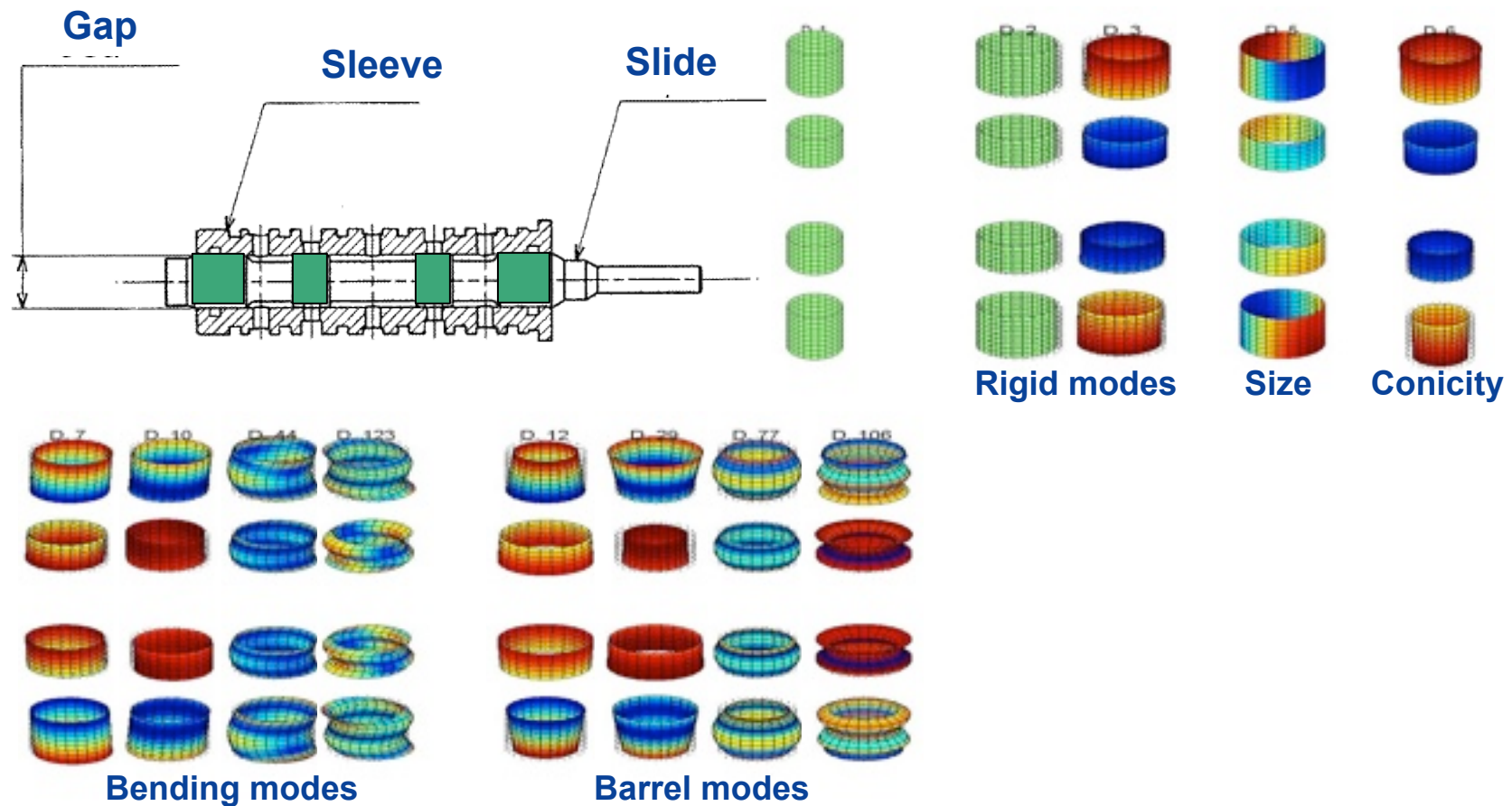
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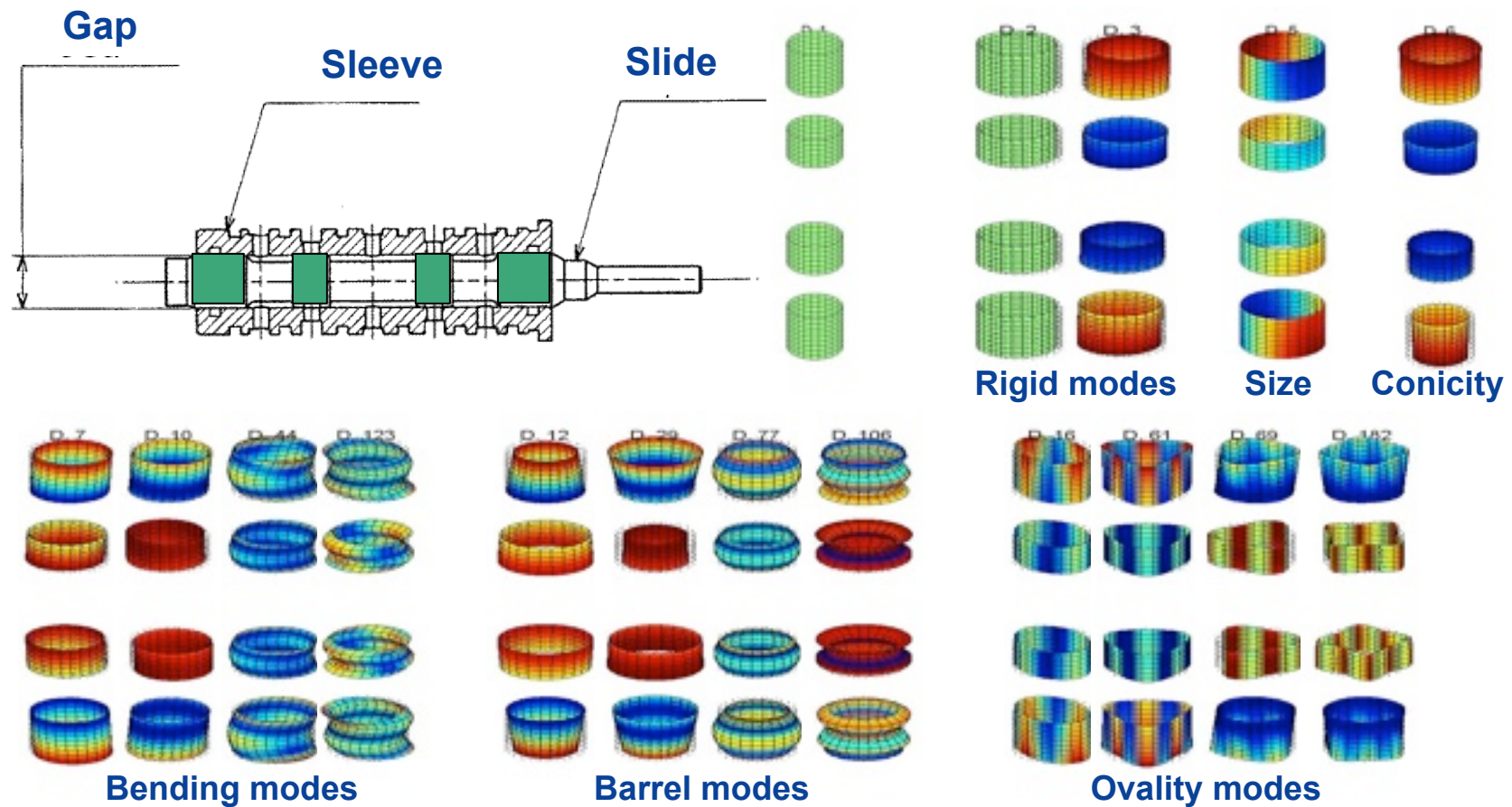
Modal parameterization

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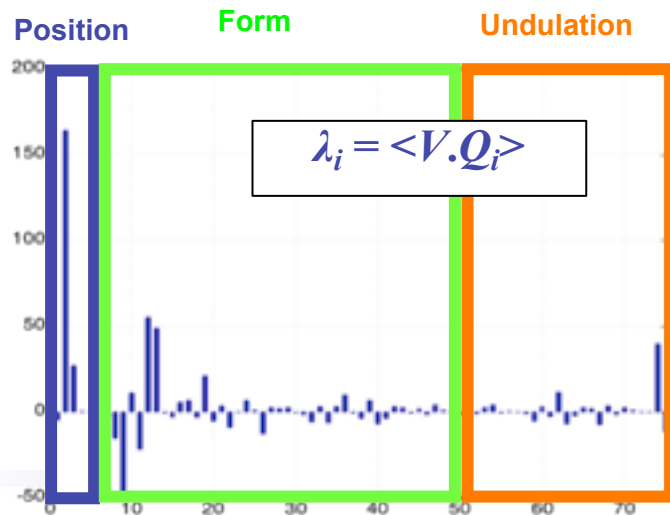


Modal parameterization

- An exhaustive basis of elementary form deviation



Modal parameterization

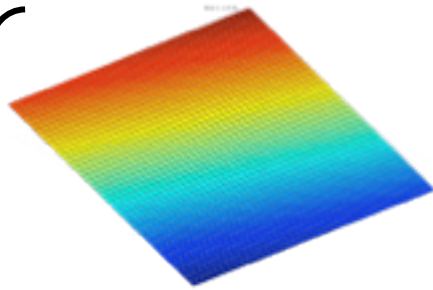


Decomposition

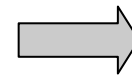
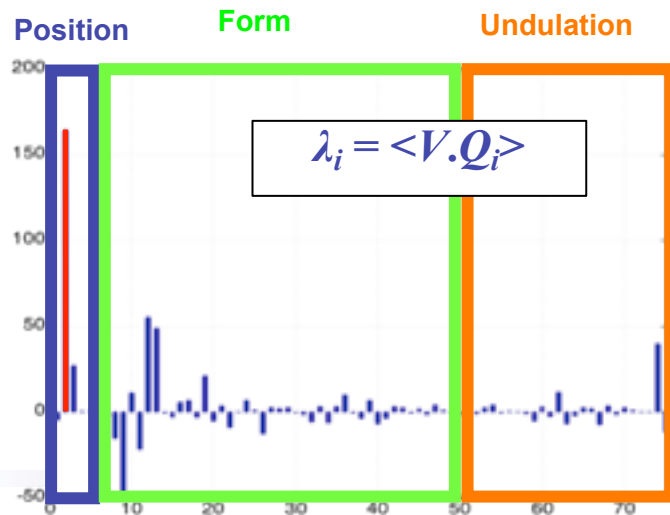
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Reconstruction

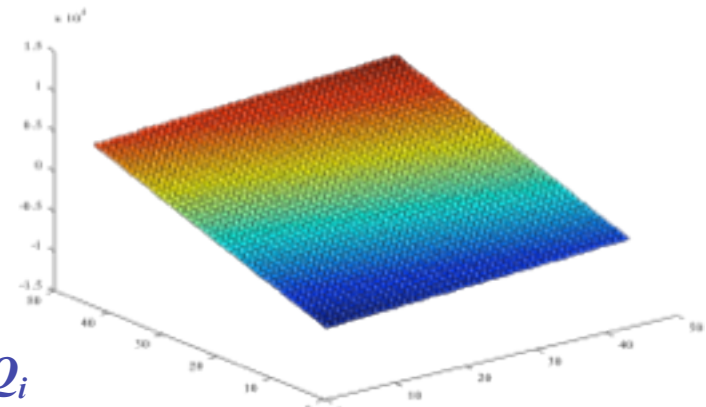
Modal parameterization



Mode 2

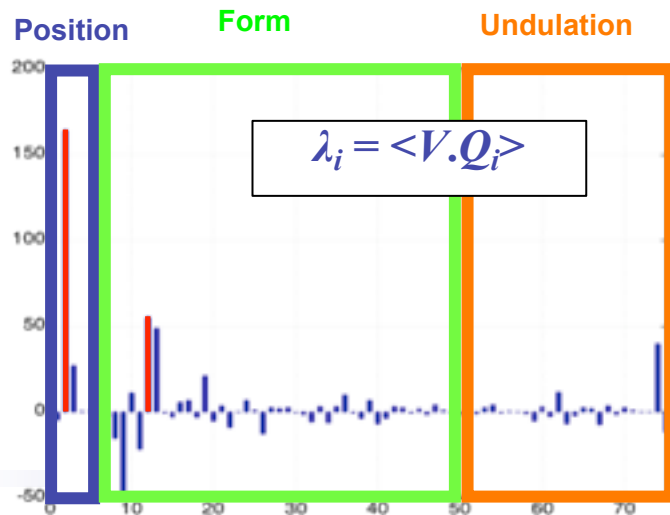
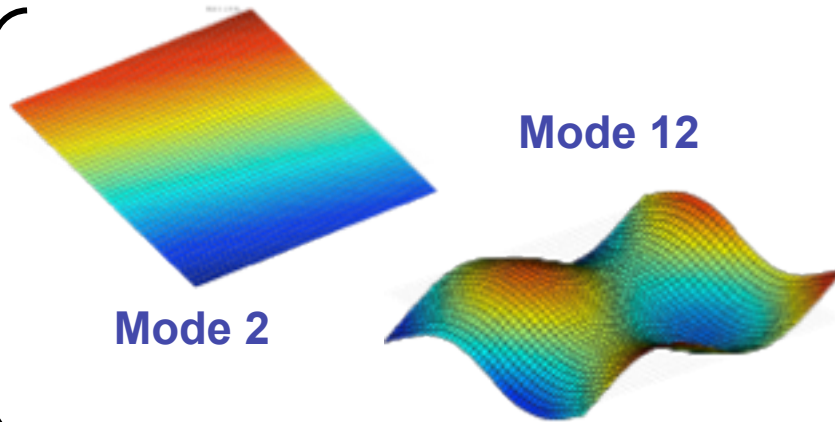


Reconstruction of the form = $\sum_{i=1}^{m=1} \lambda_i \cdot Q_i$

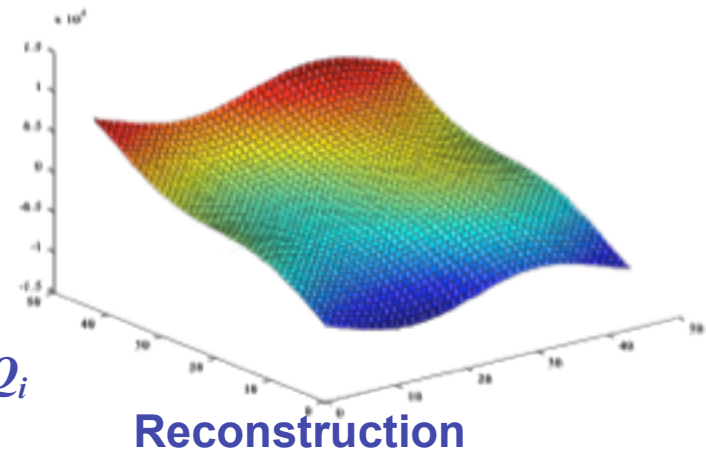


Reconstruction

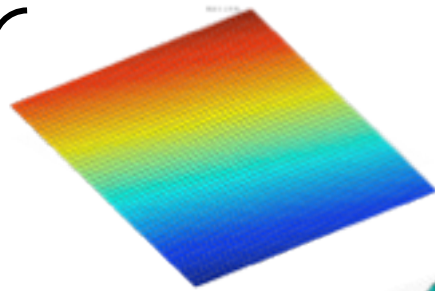
Modal parameterization



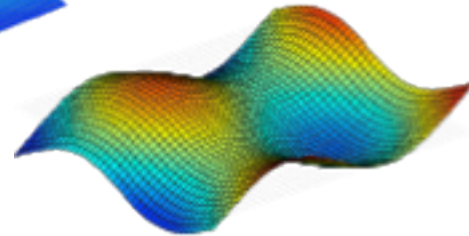
Reconstruction of the form = $\sum_{i=1}^{m=2} \lambda_i \cdot Q_i$



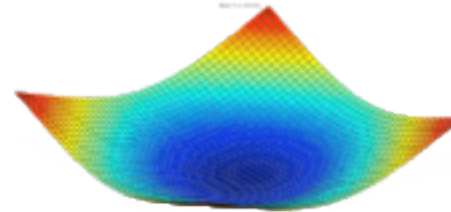
Modal parameterization



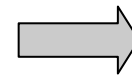
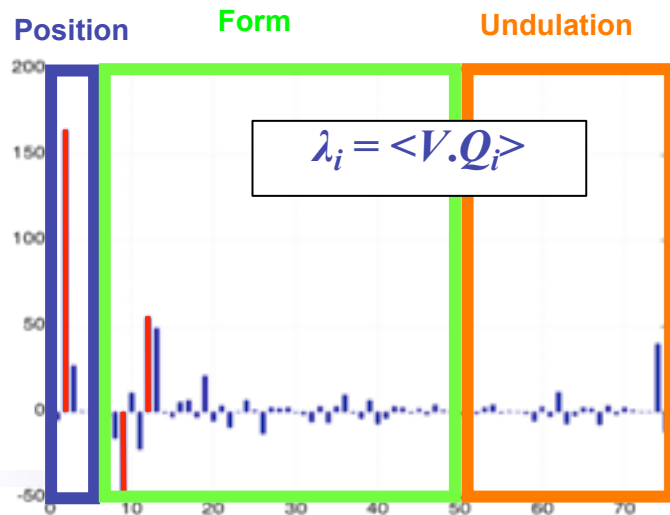
Mode 2



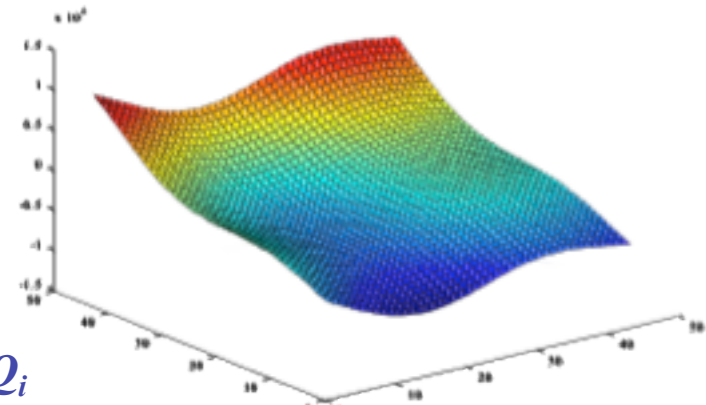
Mode 12



Mode 9

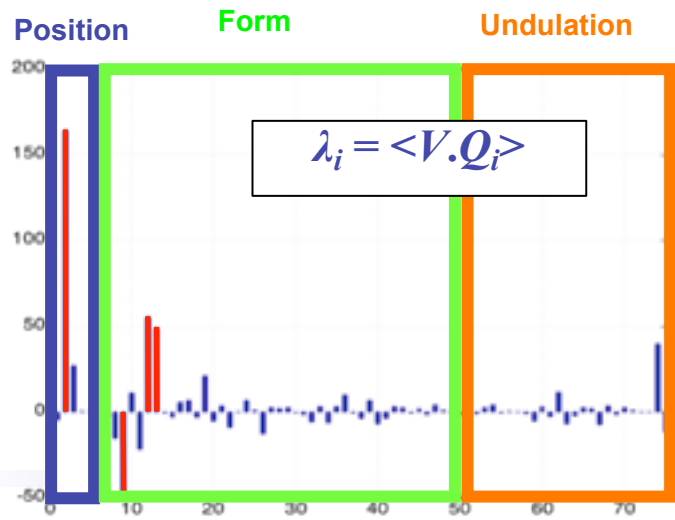
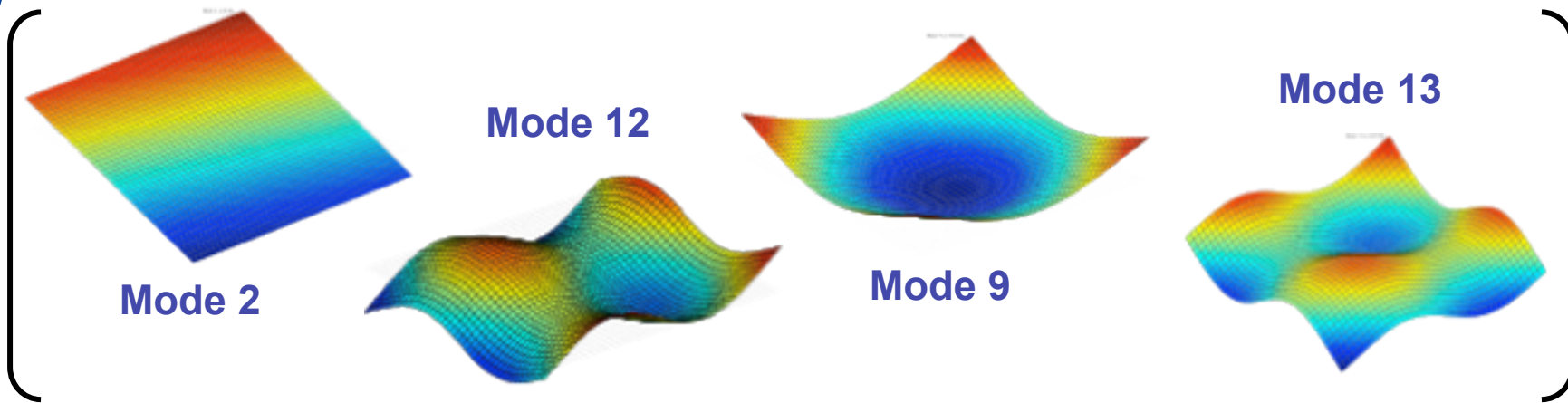


Reconstruction of the form = $\sum_{i=1}^{m=3} \lambda_i \cdot Q_i$

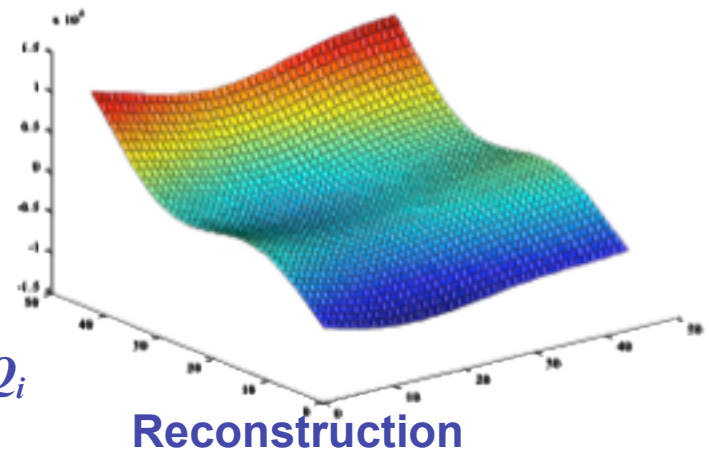


Reconstruction

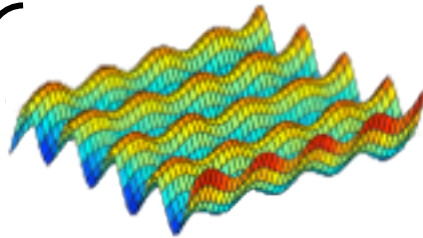
Modal parameterization



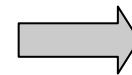
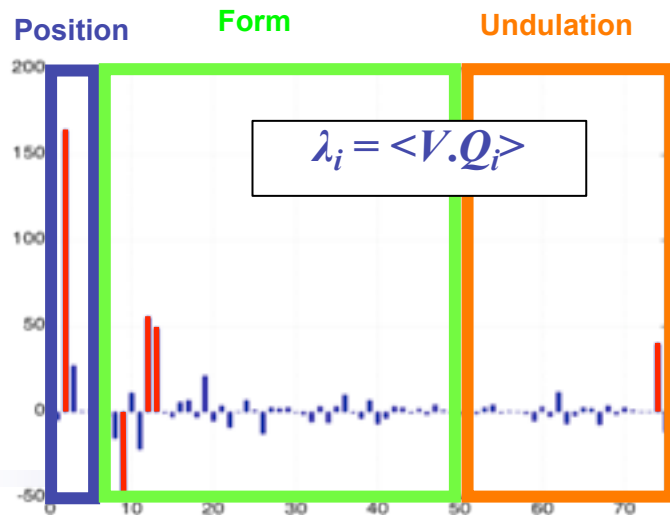
Reconstruction of the form = $\sum_{i=1}^{m=4} \lambda_i \cdot Q_i$



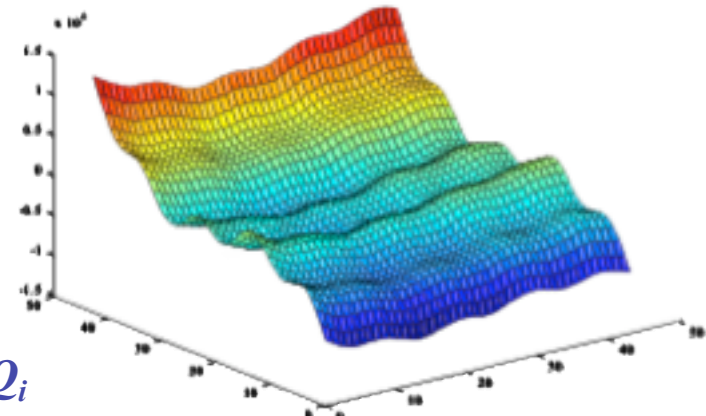
Modal parameterization



Mode 74

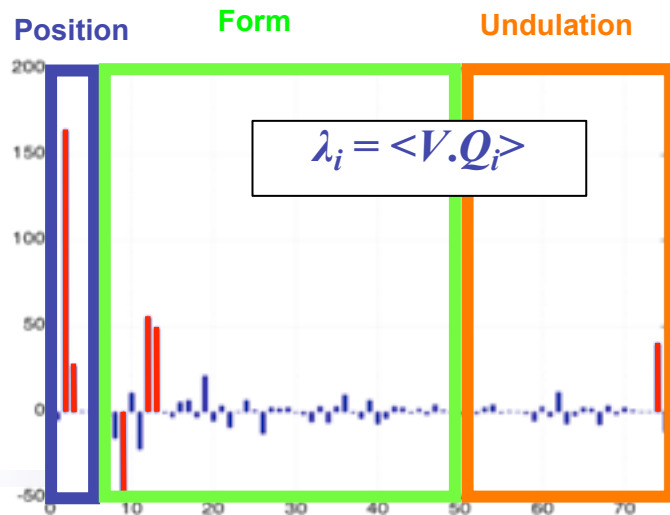
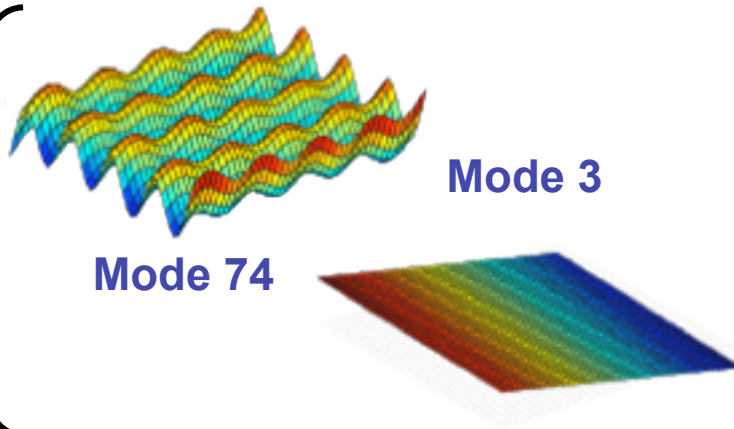


Reconstruction of the form = $\sum_{i=1}^{m=5} \lambda_i \cdot Q_i$

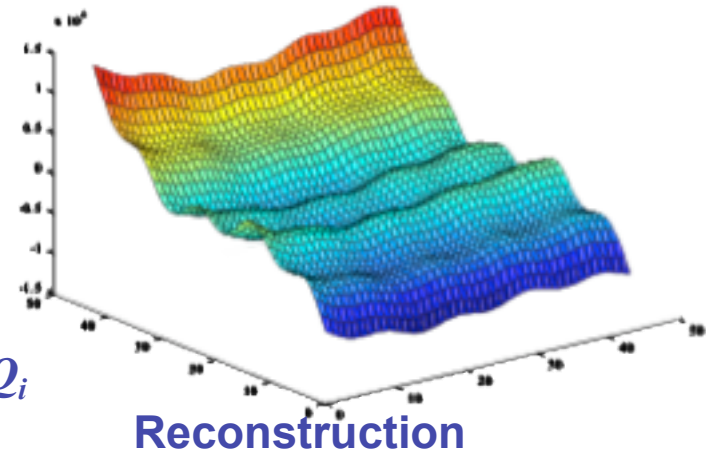


Reconstruction

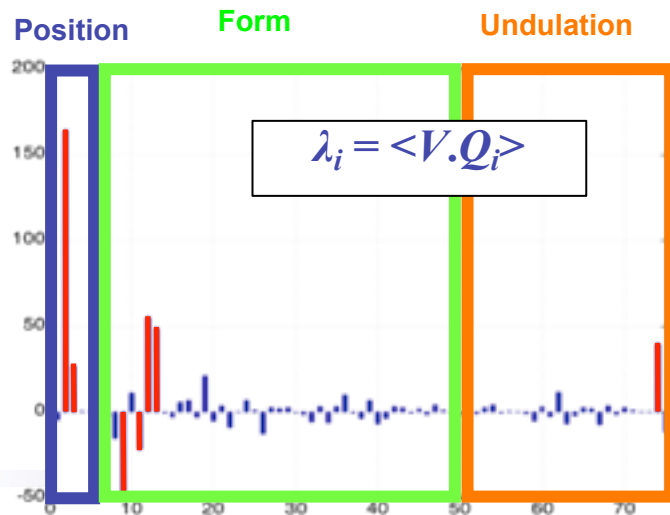
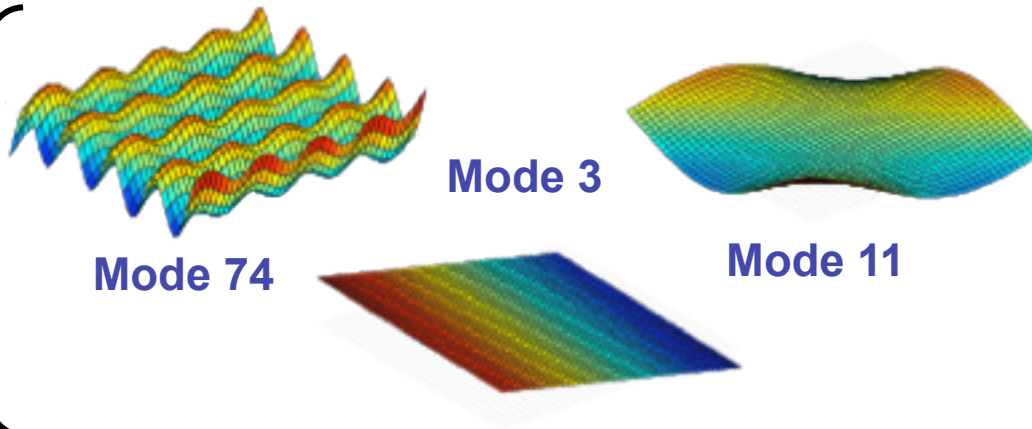
Modal parameterization



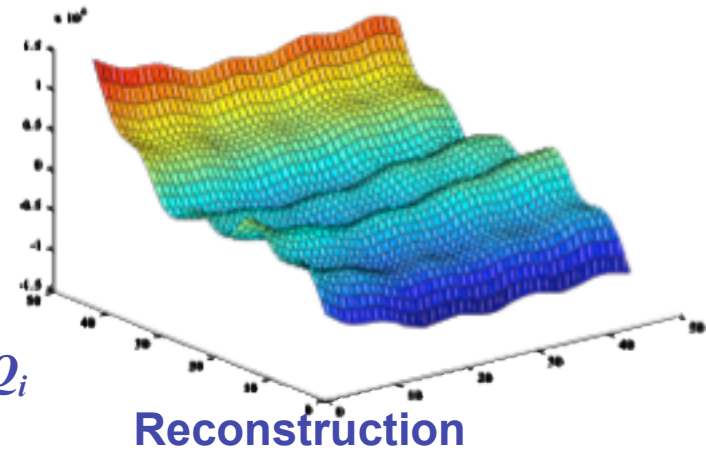
Reconstruction of the form = $\sum_{i=1}^{m=6} \lambda_i \cdot Q_i$



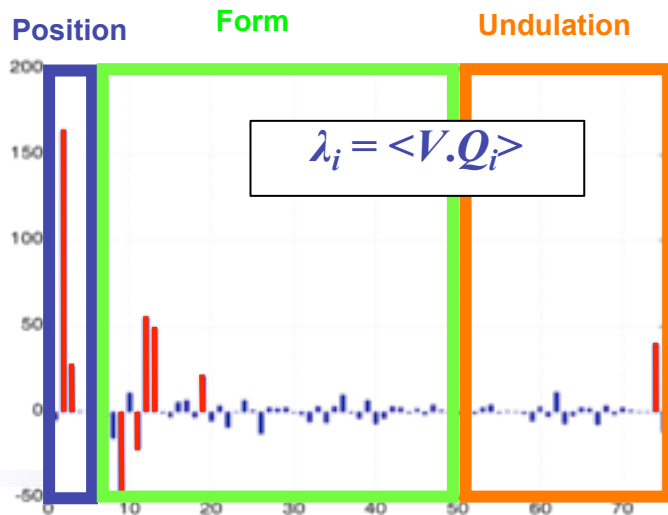
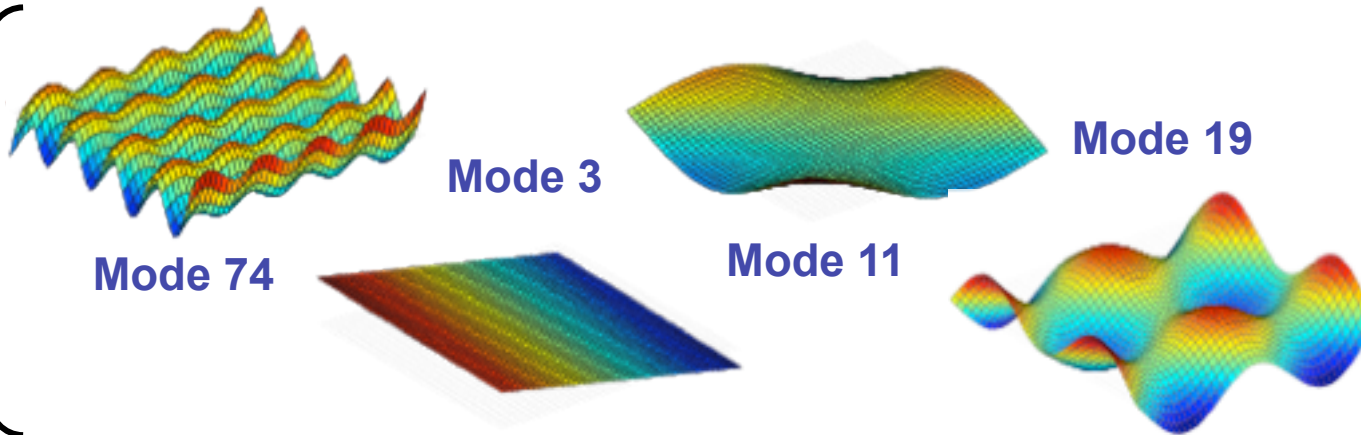
Modal parameterization



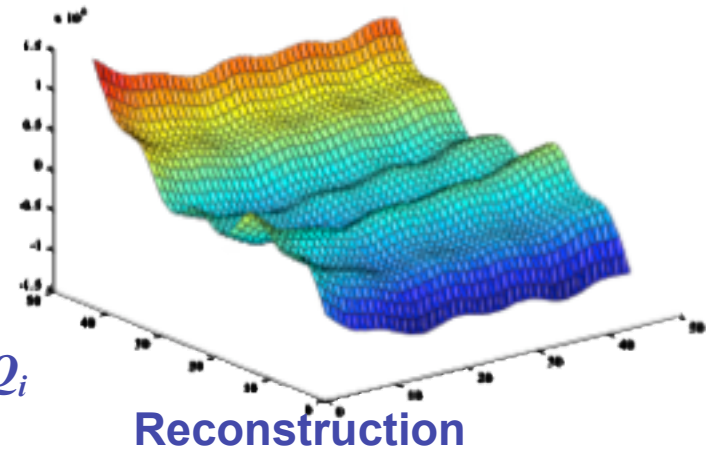
Reconstruction of the form = $\sum_{i=1}^{m=7} \lambda_i \cdot Q_i$



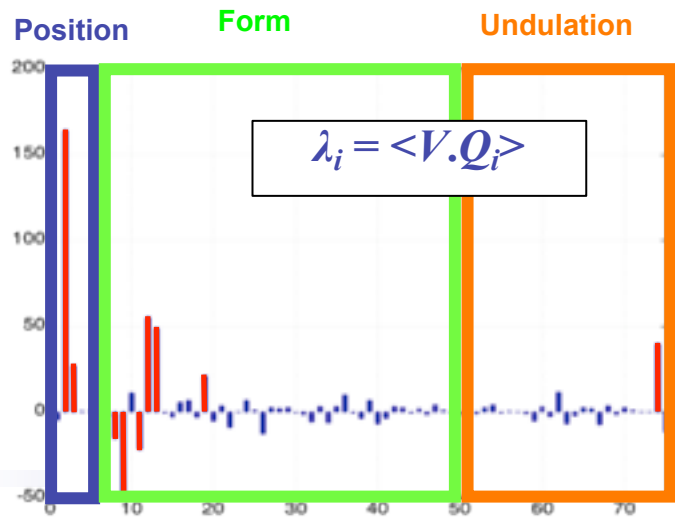
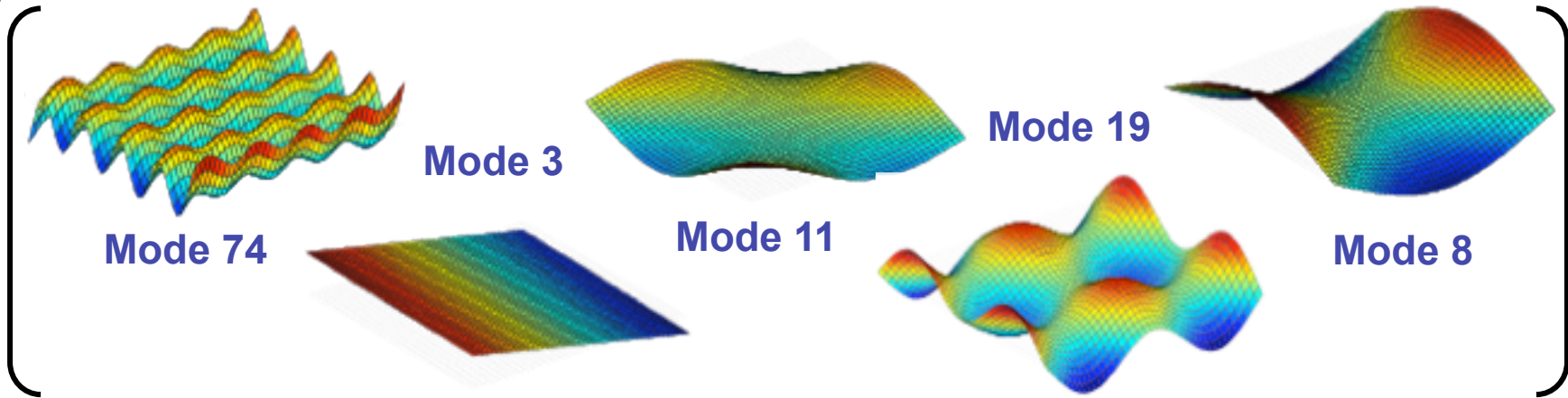
Modal parameterization



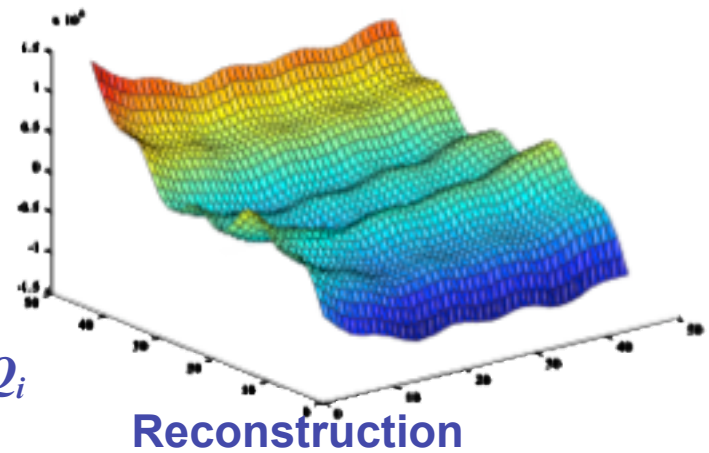
Reconstruction of the form = $\sum_{i=1}^{m=8} \lambda_i \cdot Q_i$



Modal parameterization



Reconstruction of the form = $\sum_{i=1}^{m=9} \lambda_i \cdot Q_i$

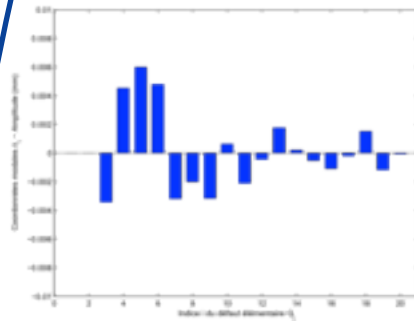


Decomposition

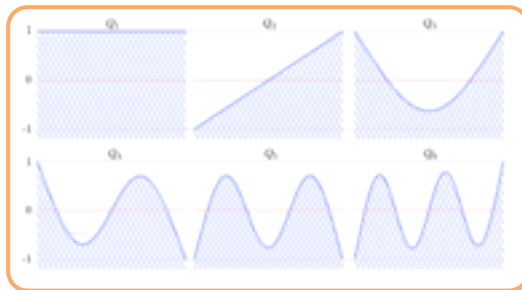
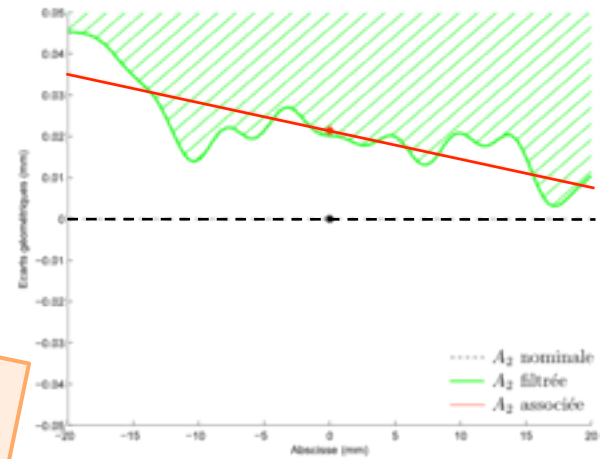
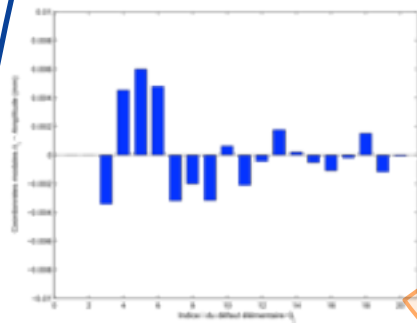
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Modal parameterization and GPS criterion

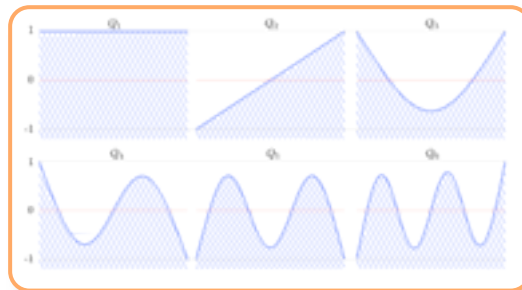
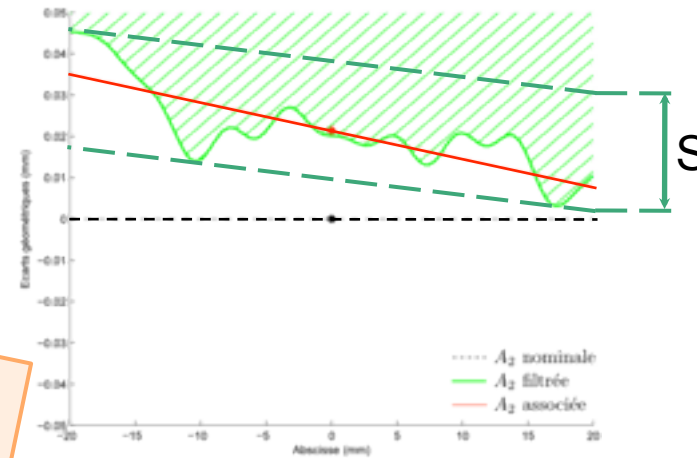
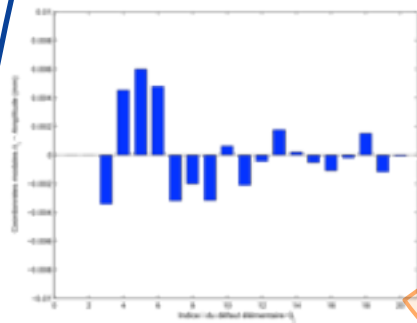
Modal parameterization and GPS criterion



Modal parameterization and GPS criterion

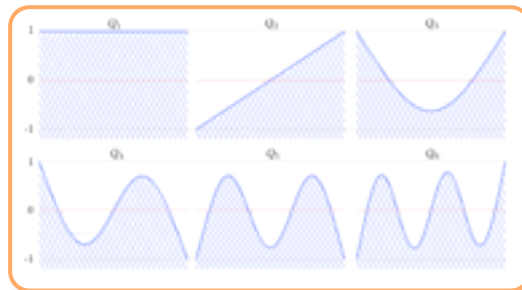
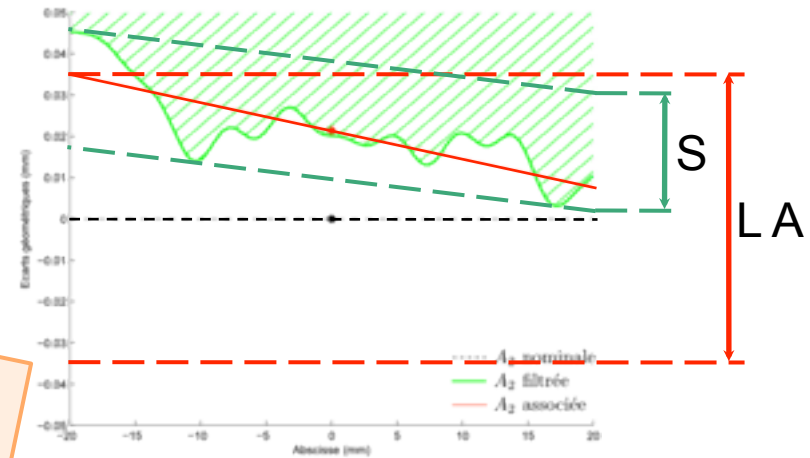
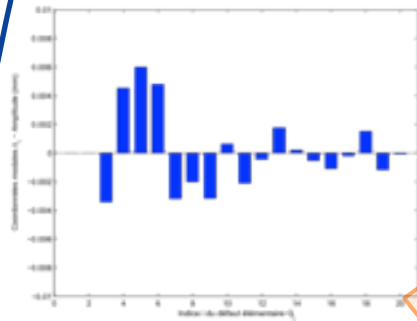


Modal parameterization and GPS criterion



S = Strength : *GPS définition*

Modal parameterization and GPS criterion



S = Strength : *GPS définition*

LA = Localisation of the Associated geometry : *GPS définition applied to the associated geometry*



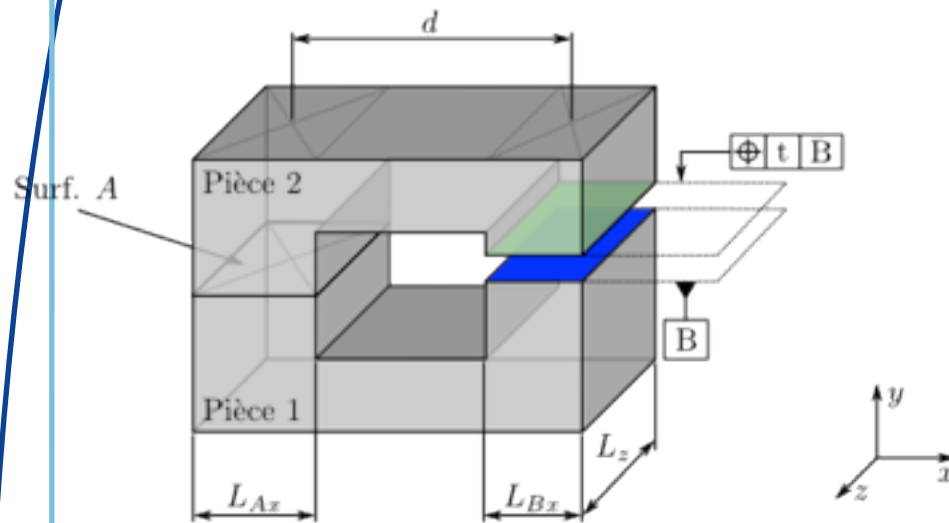
Influence of form deviations in parts stack up

Assembly and form deviations

Assumptions

- Rigid parts
- No clearance
- Positioning force

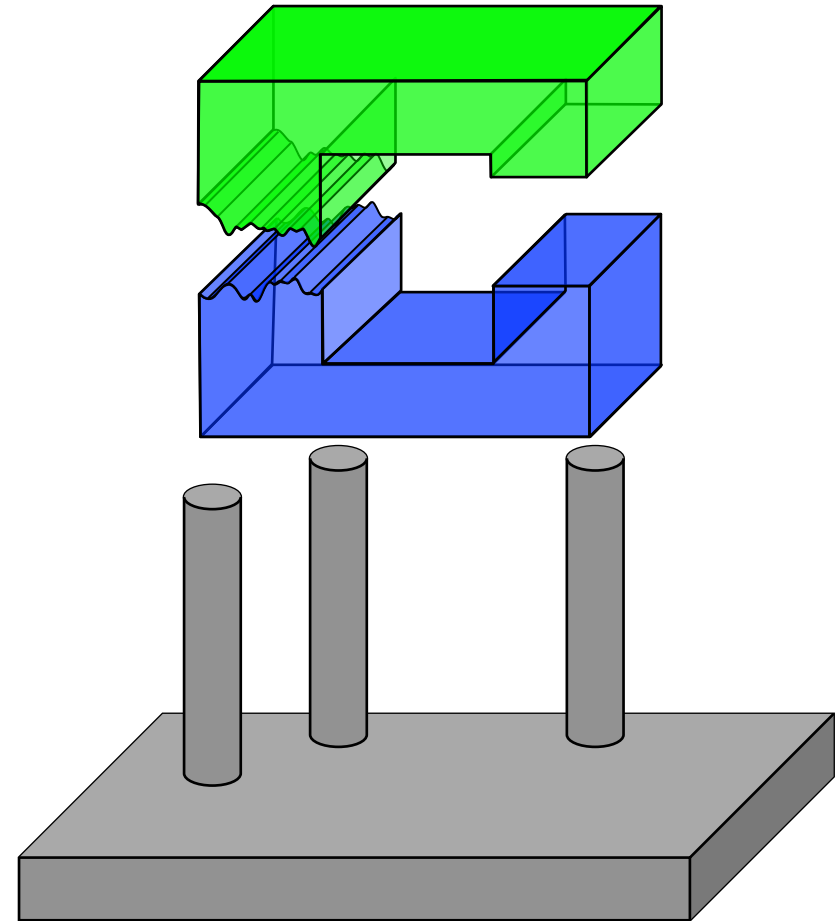
→ Considering the form deviations



$$L_{Ax} = 40 \text{ mm}$$

$$L_{Bx} = 20 \text{ mm}$$

$$L_z = 40 \text{ mm}$$

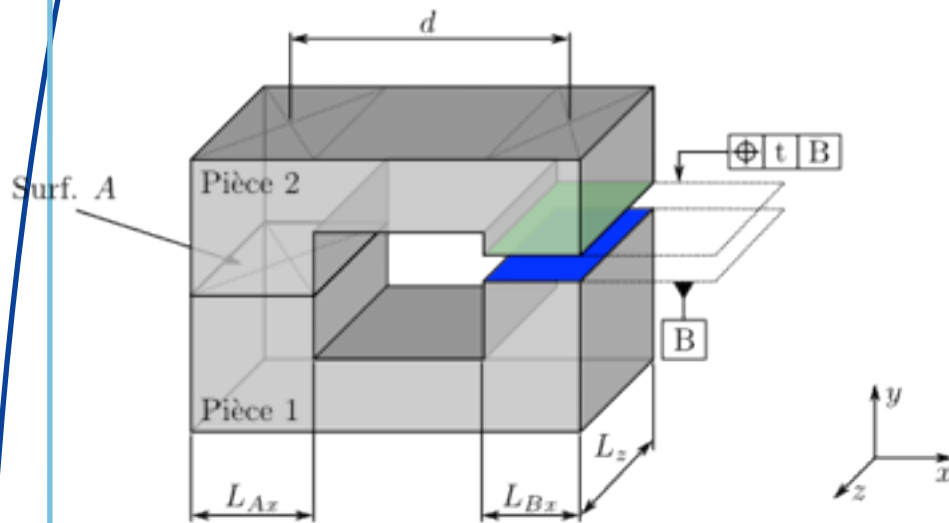


Assembly and form deviations

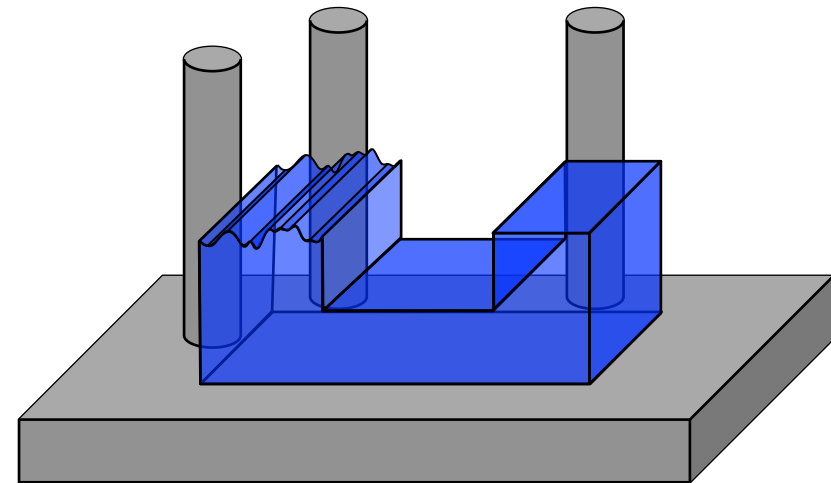
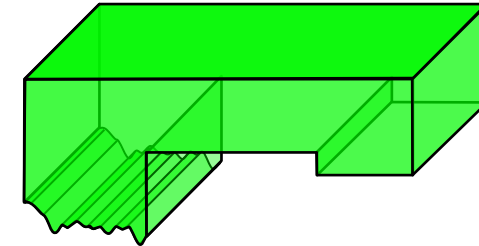
Assumptions

- Rigid parts
- No clearance
- Positioning force

→ Considering the form deviations



$L_{Ax} = 40 \text{ mm}$
 $L_{Bx} = 20 \text{ mm}$
 $L_z = 40 \text{ mm}$

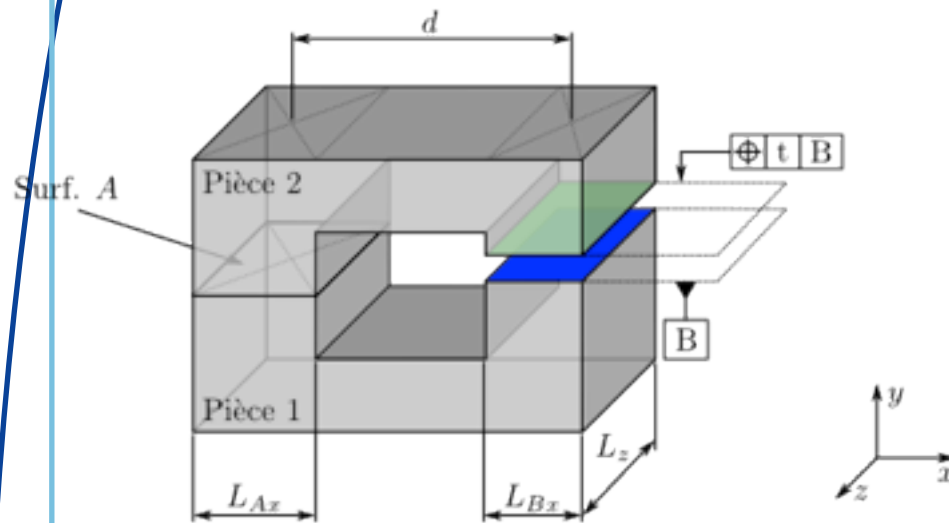


Assembly and form deviations

Assumptions

- Rigid parts
- No clearance
- Positioning force

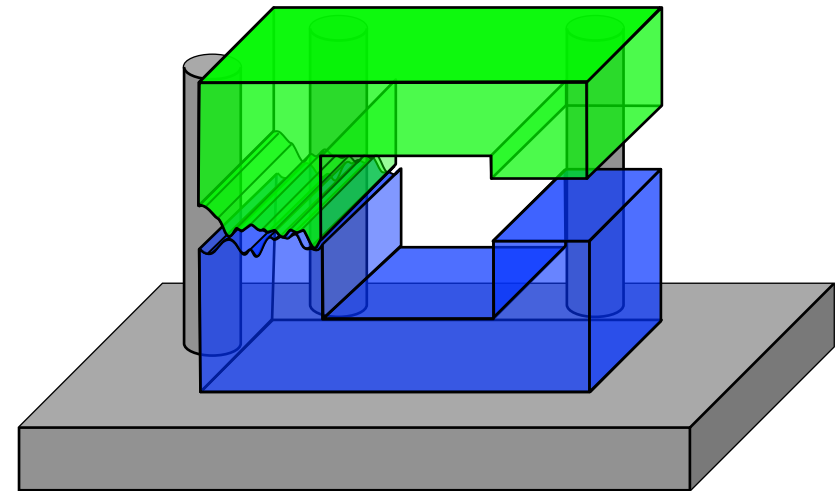
→ Considering the form deviations



$$L_{Ax} = 40 \text{ mm}$$

$$L_{Bx} = 20 \text{ mm}$$

$$L_z = 40 \text{ mm}$$

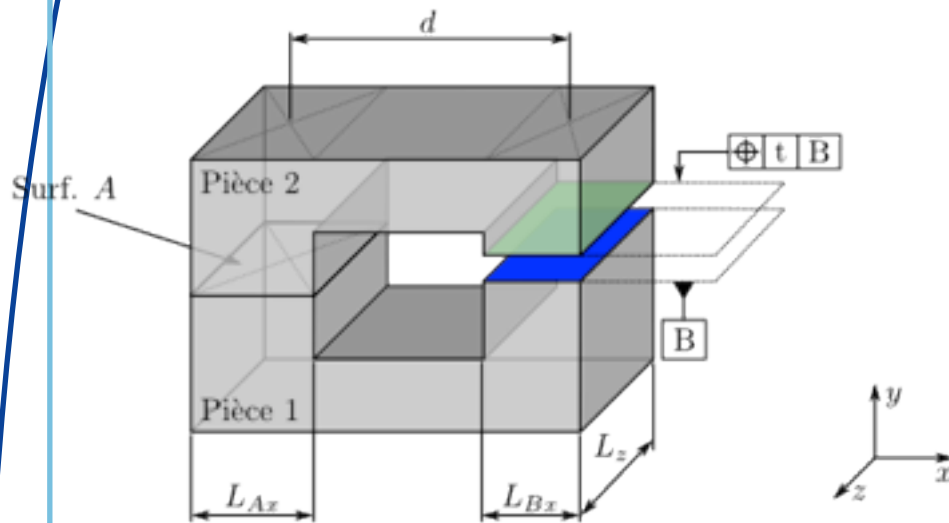


Assembly and form deviations

Assumptions

- Rigid parts
- No clearance
- Positioning force

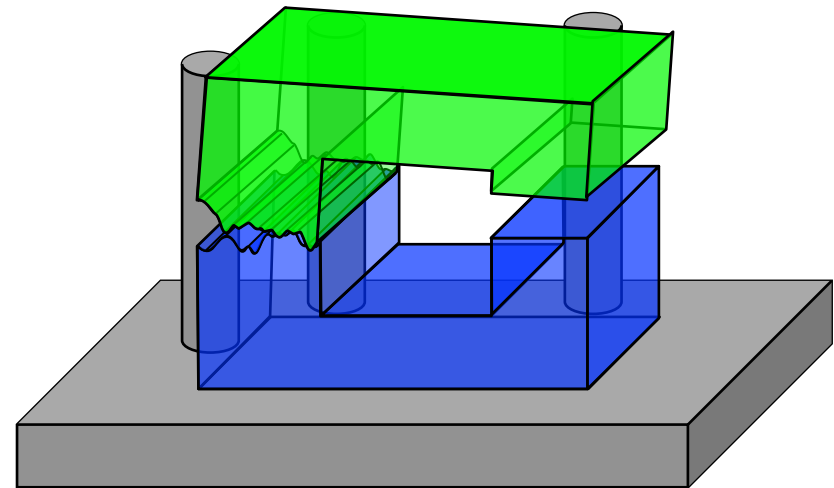
→ Considering the form deviations



$$L_{Ax} = 40 \text{ mm}$$

$$L_{Bx} = 20 \text{ mm}$$

$$L_z = 40 \text{ mm}$$

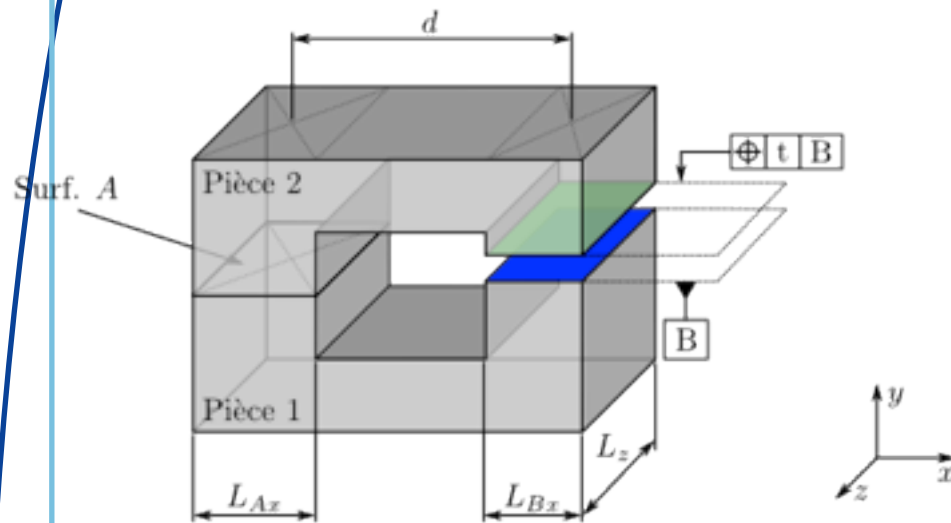


Assembly and form deviations

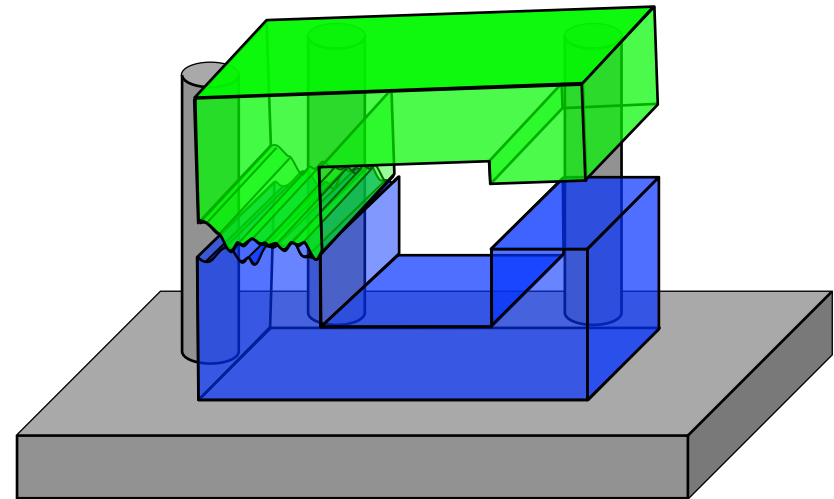
Assumptions

- Rigid parts
- No clearance
- Positioning force

→ Considering the form deviations



$$\begin{aligned} L_{Ax} &= 40 \text{ mm} \\ L_{Bx} &= 20 \text{ mm} \\ L_z &= 40 \text{ mm} \end{aligned}$$

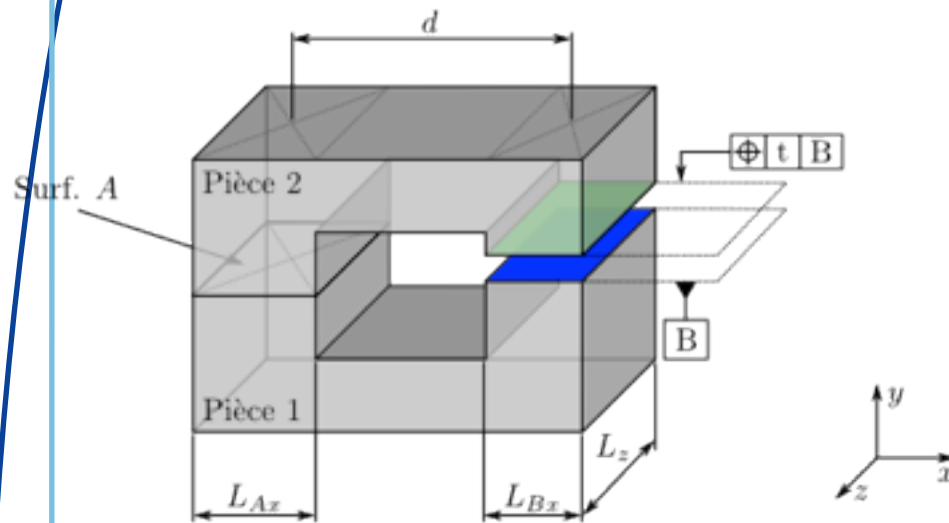


Assembly and form deviations

Assumptions

- Rigid parts
- No clearance
- Positioning force

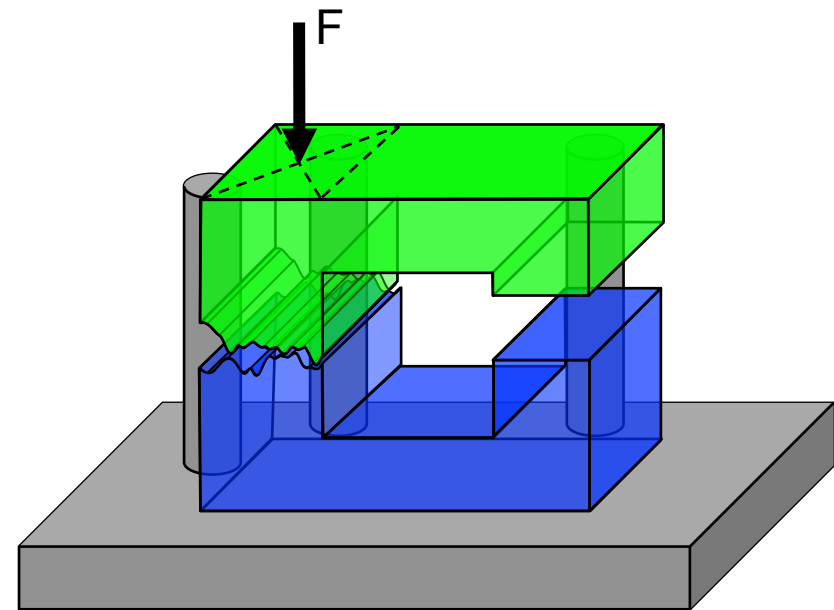
→ Considering the form deviations



$$L_{Ax} = 40 \text{ mm}$$

$$L_{Bx} = 20 \text{ mm}$$

$$L_z = 40 \text{ mm}$$

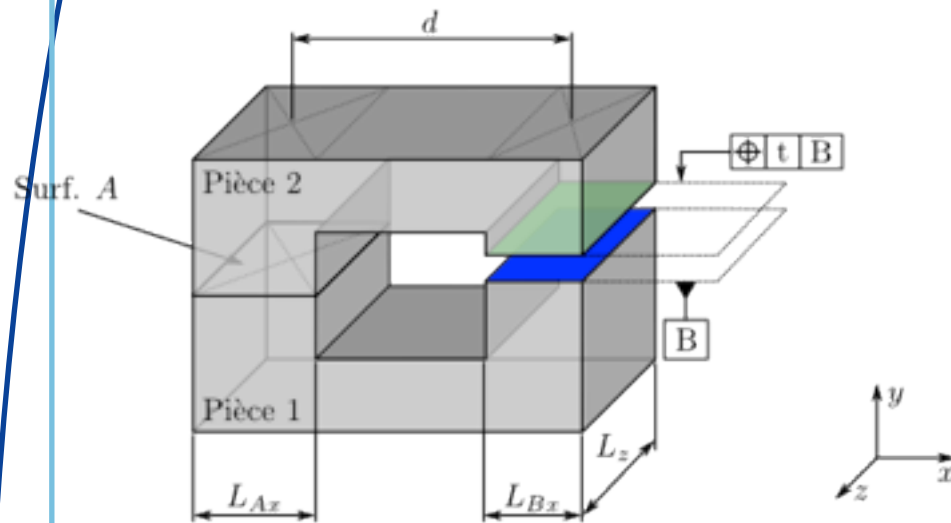


Assembly and form deviations

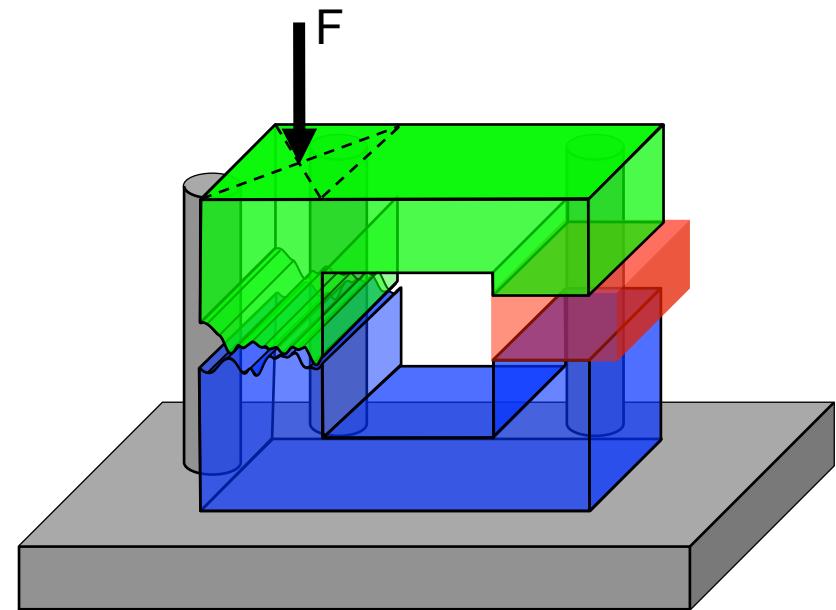
Assumptions

- Rigid parts
- No clearance
- Positioning force

→ Considering the form deviations

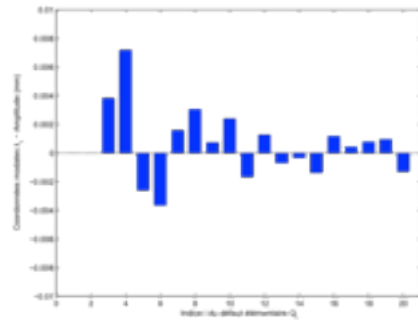
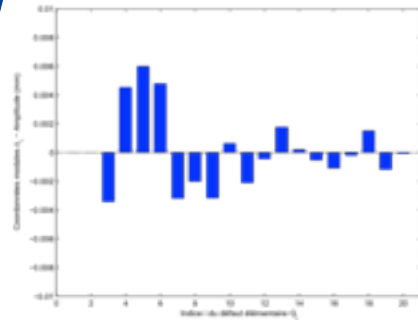


$$\begin{aligned} L_{Ax} &= 40 \text{ mm} \\ L_{Bx} &= 20 \text{ mm} \\ L_z &= 40 \text{ mm} \end{aligned}$$

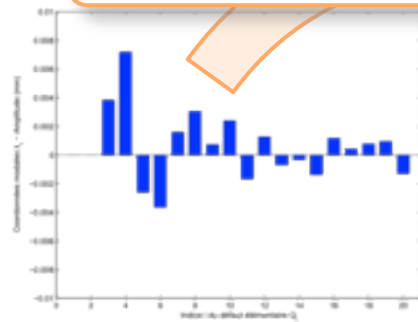
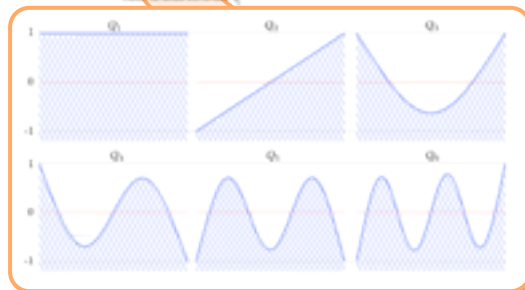
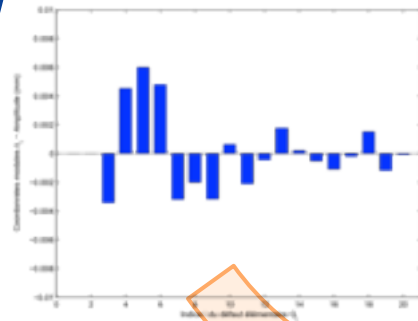


Assembly and form deviations

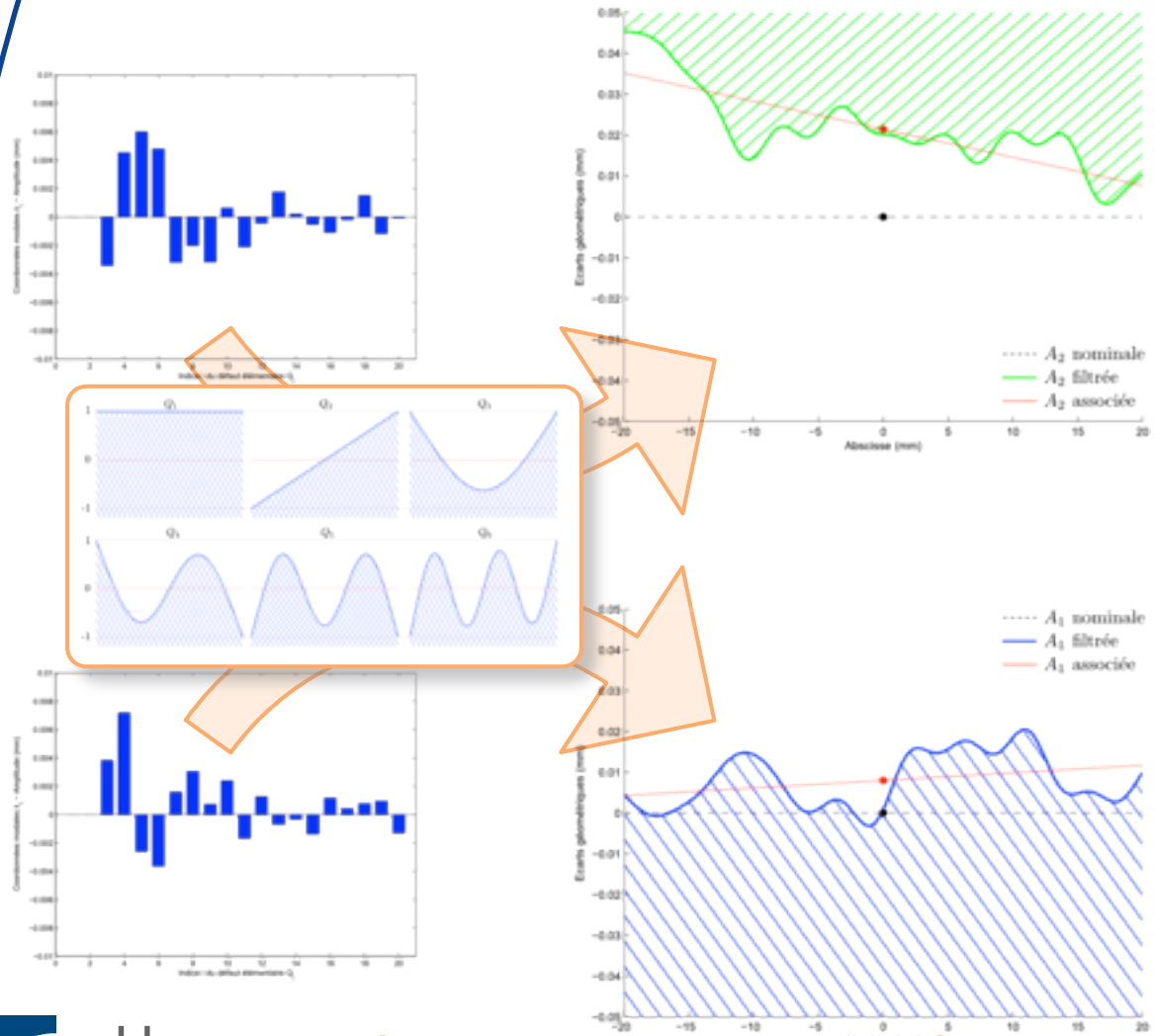
Assembly and form deviations



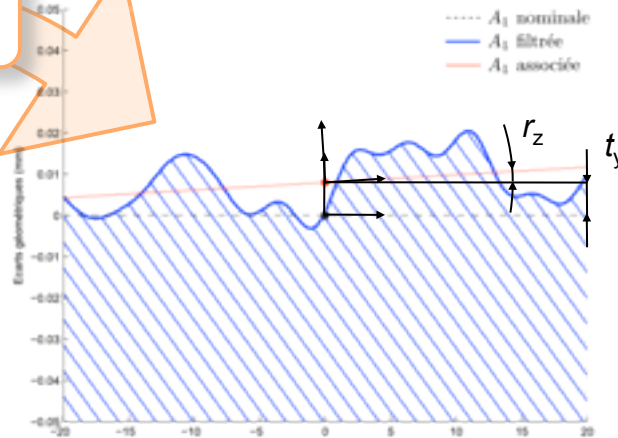
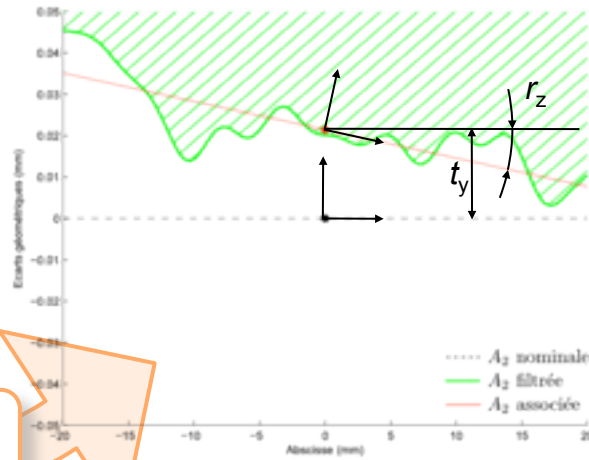
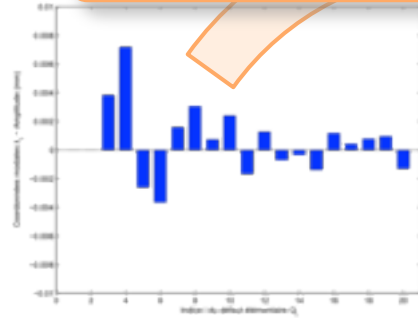
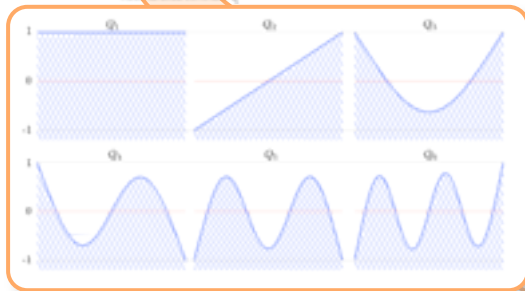
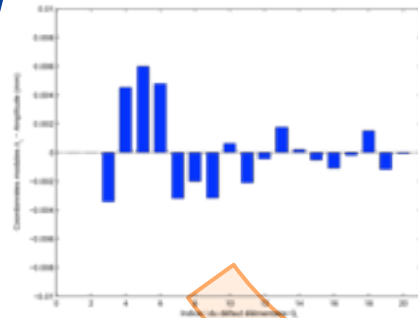
Assembly and form deviations



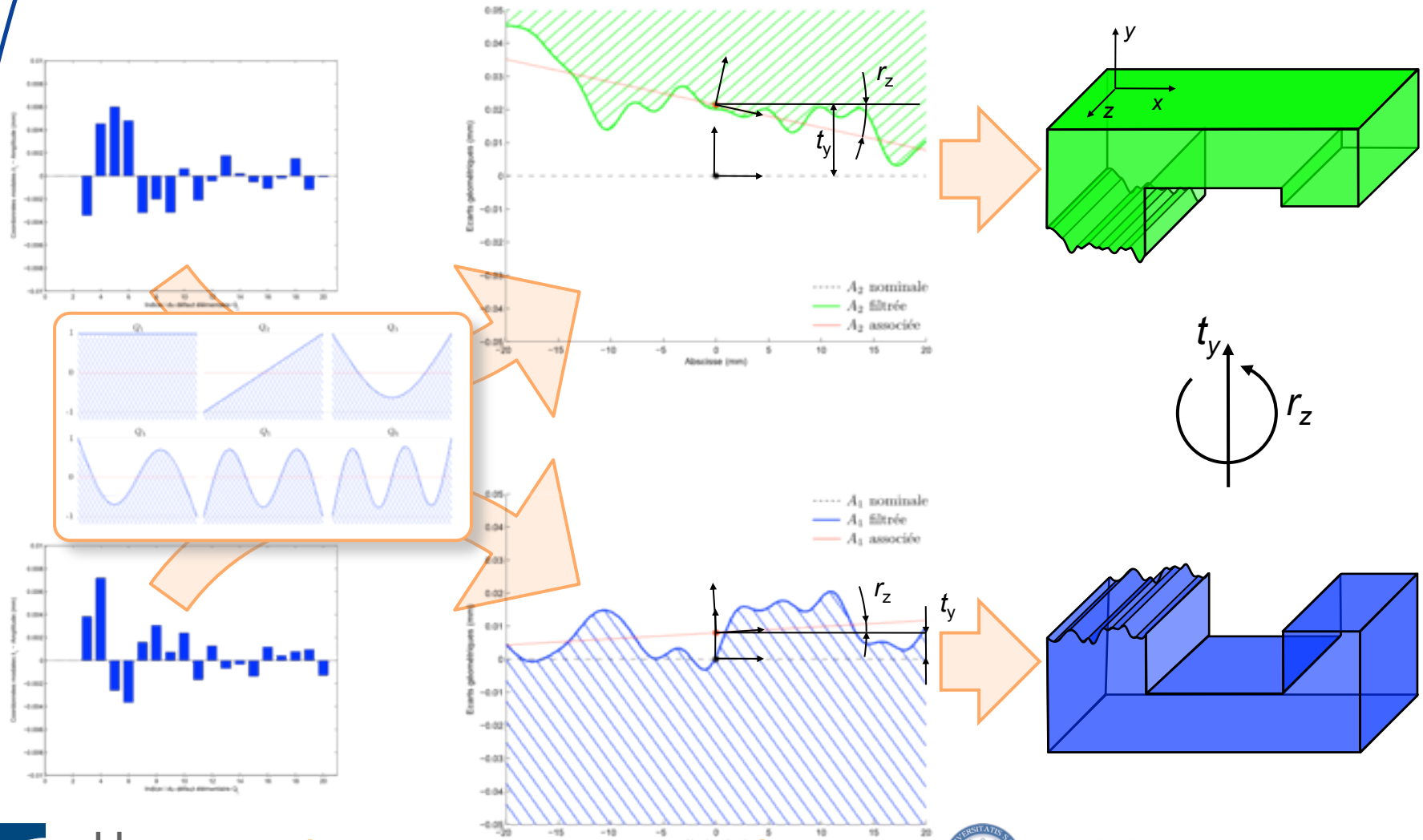
Assembly and form deviations



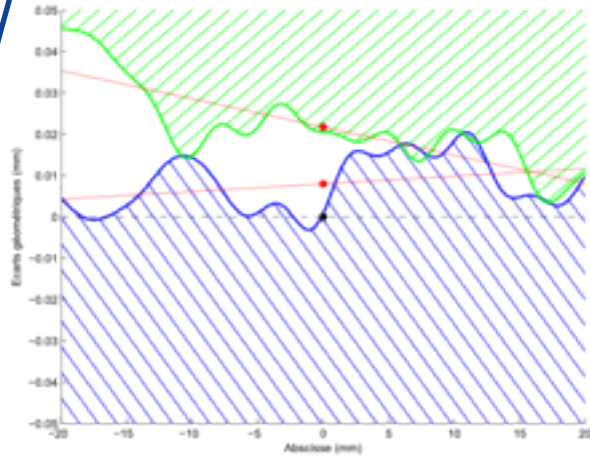
Assembly and form deviations



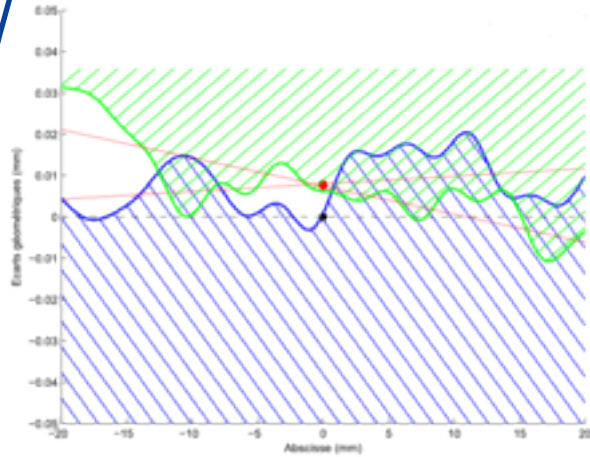
Assembly and form deviations



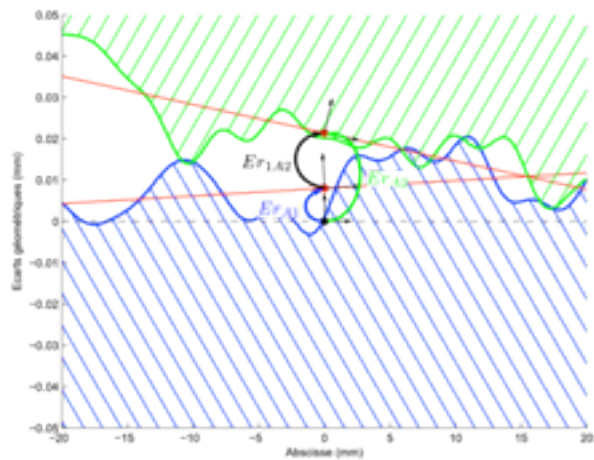
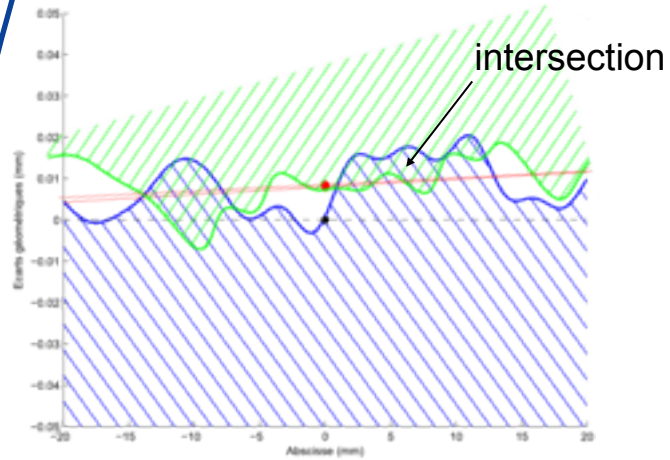
Assembly of rigid deviations only (without form deviations)



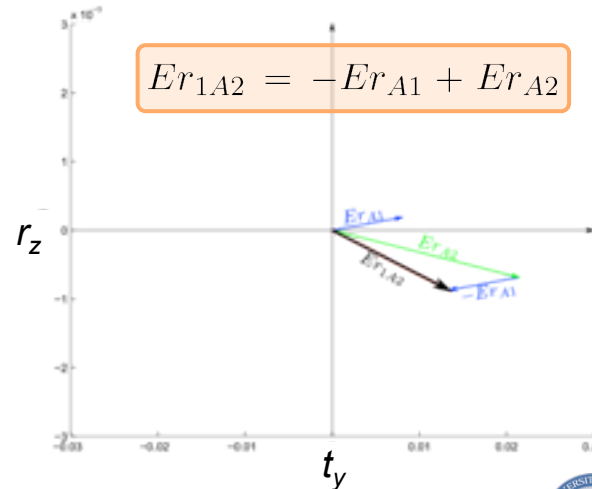
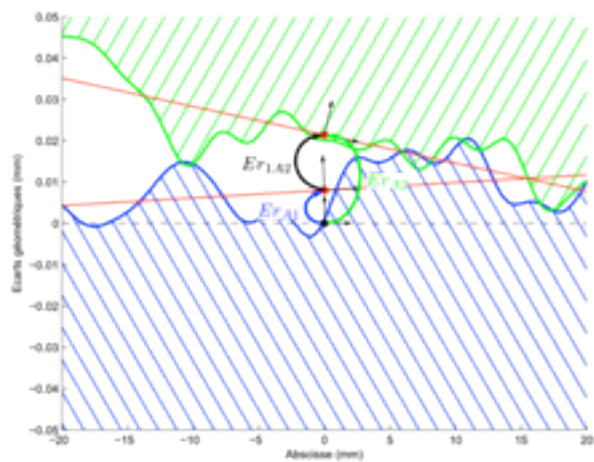
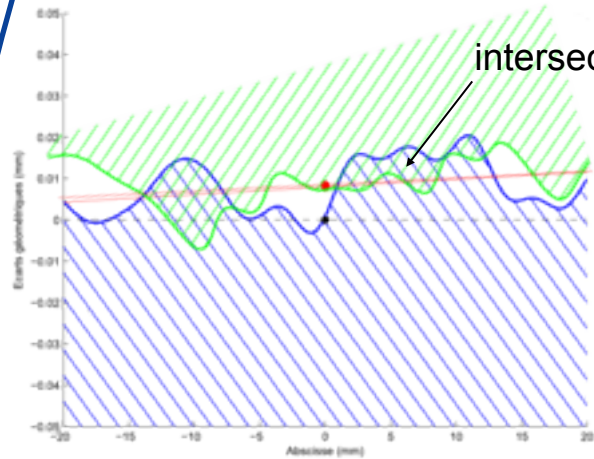
Assembly of rigid deviations only (without form deviations)



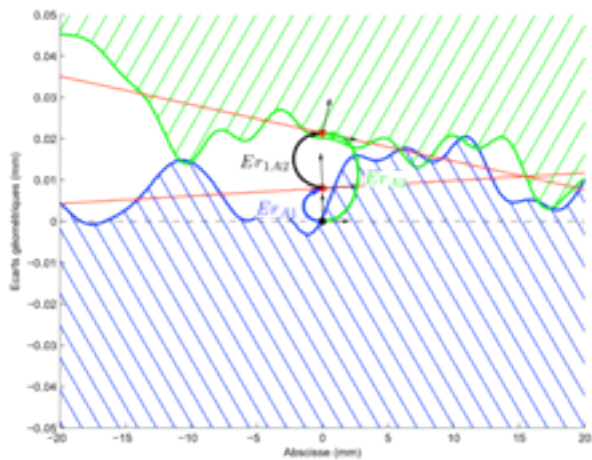
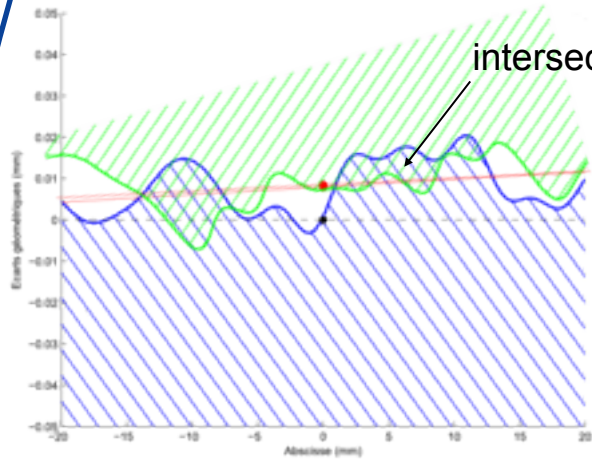
Assembly of rigid deviations only (without form deviations)



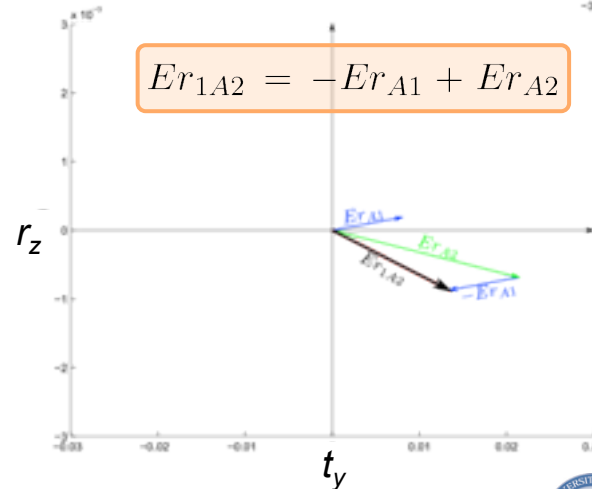
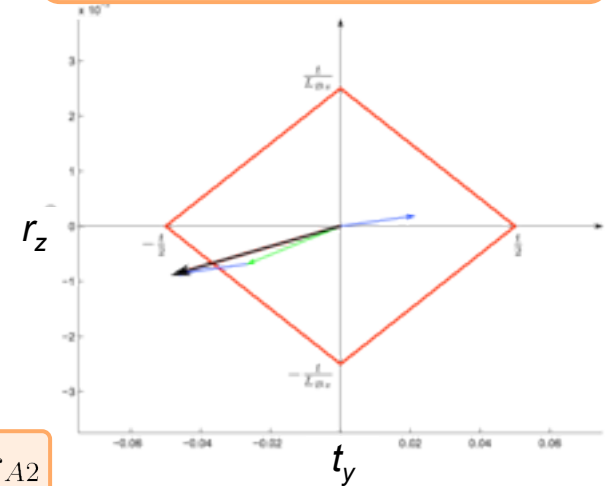
Assembly of rigid deviations only (without form deviations)



Assembly of rigid deviations only (without form deviations)

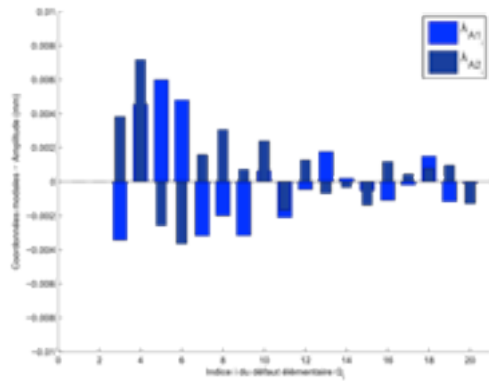


$$\begin{cases} -\frac{t}{2} \leq t_y - \frac{L_{Bx}}{2} r_z \leq \frac{t}{2} \\ -\frac{t}{2} \leq t_y + \frac{L_{Bx}}{2} r_z \leq \frac{t}{2} \end{cases}$$

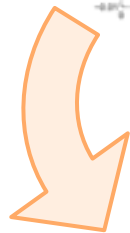
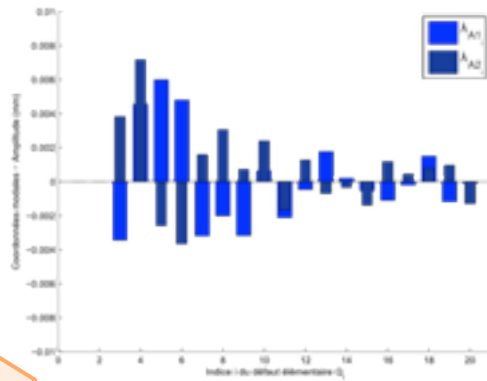


At the functional requirement

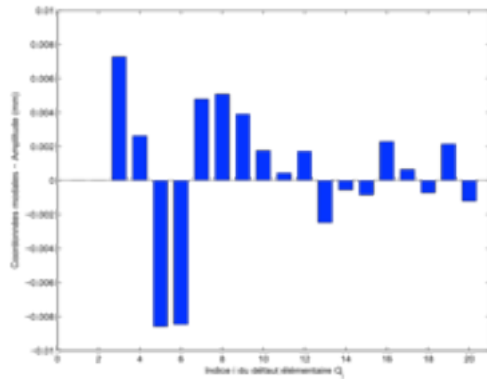
Assembly of form deviations only (without rigid deviations)



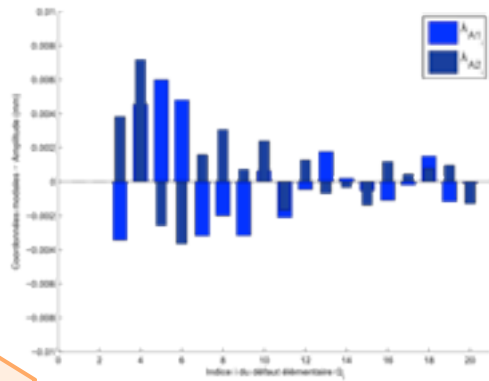
Assembly of form deviations only (without rigid deviations)



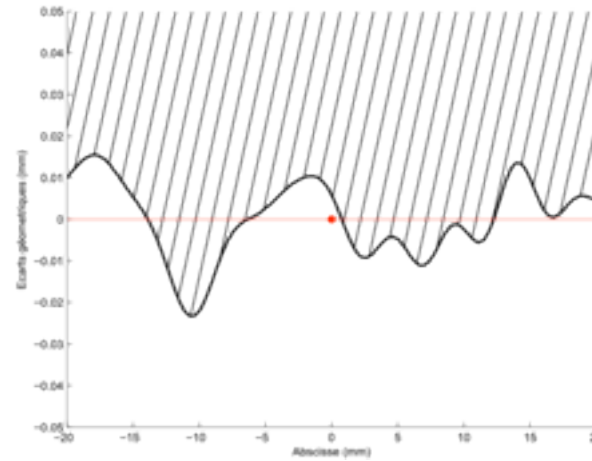
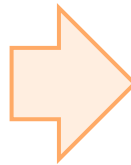
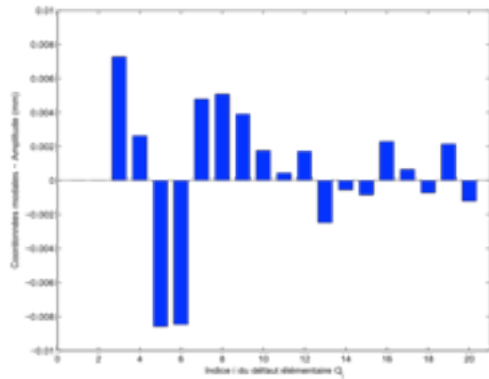
$$\lambda_{1A2_i} = \lambda_{A2_i} - \lambda_{A1_i}$$



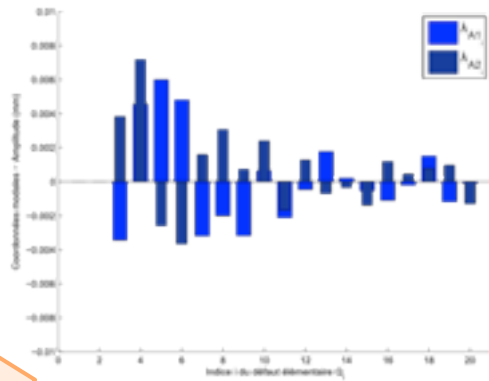
Assembly of form deviations only (without rigid deviations)



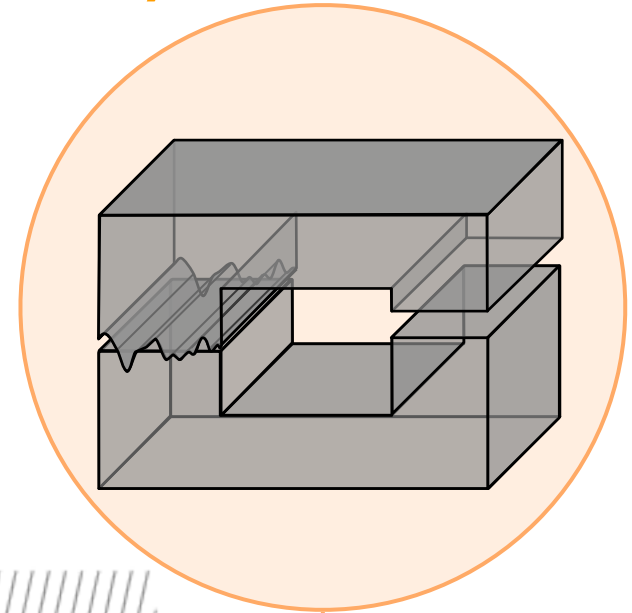
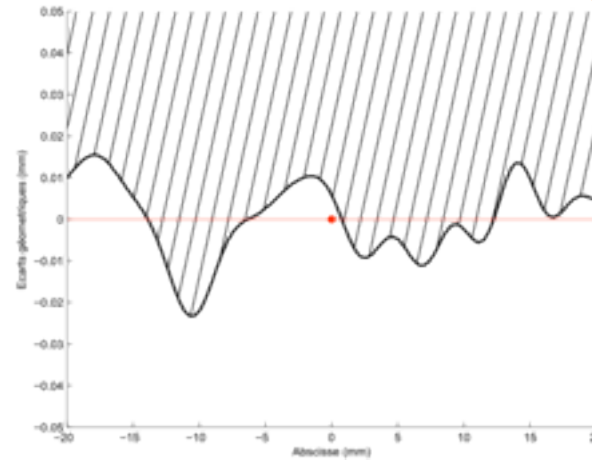
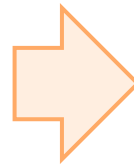
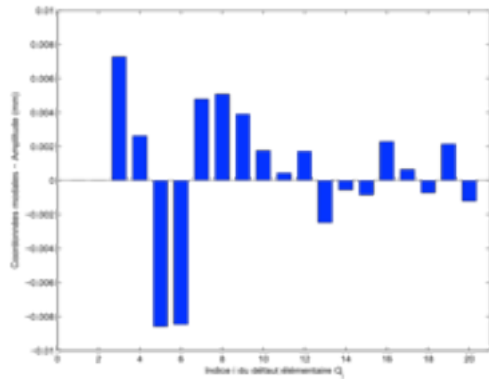
$$\lambda_{1A2_i} = \lambda_{A2_i} - \lambda_{A1_i}$$



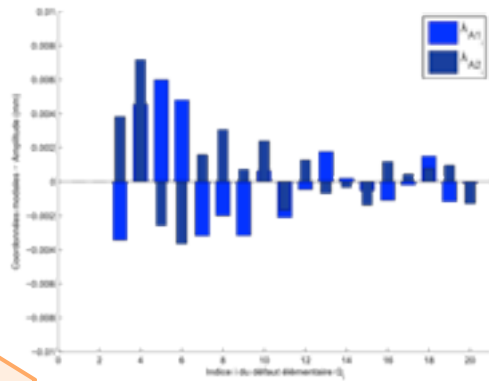
Assembly of form deviations only (without rigid deviations)



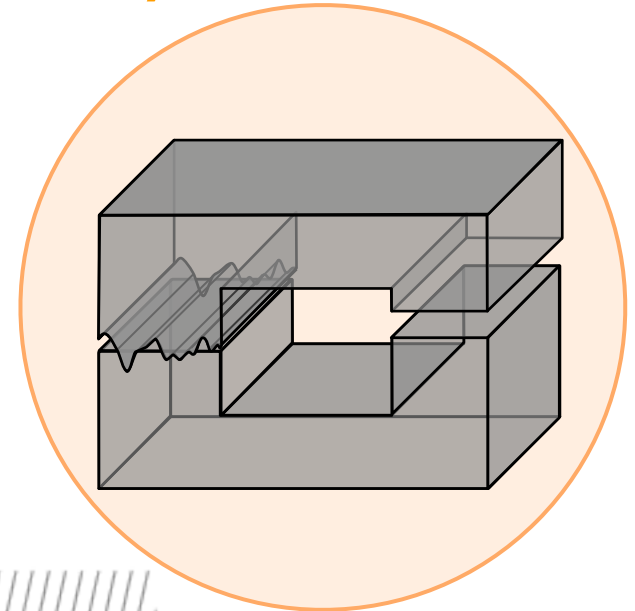
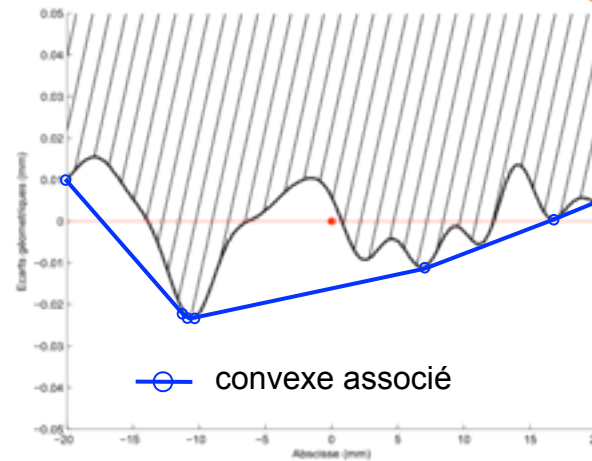
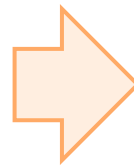
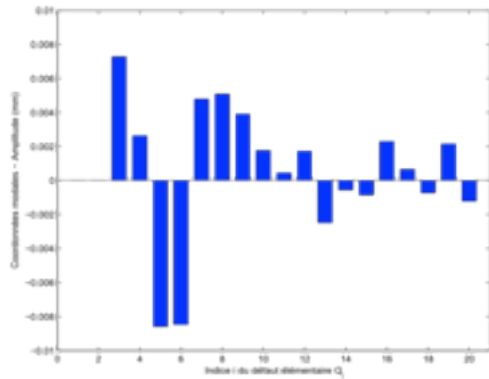
$$\lambda_{1A2_i} = \lambda_{A2_i} - \lambda_{A1_i}$$



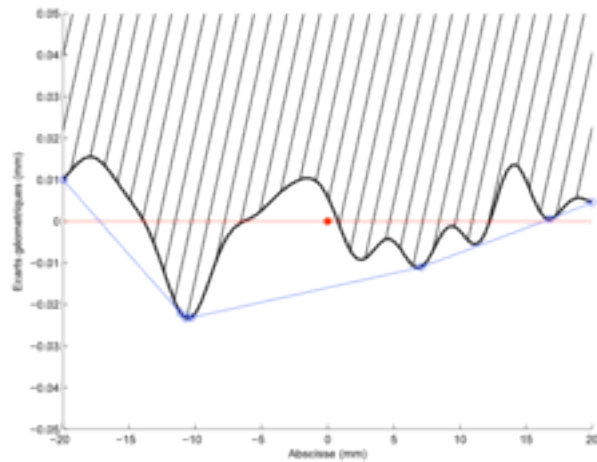
Assembly of form deviations only (without rigid deviations)



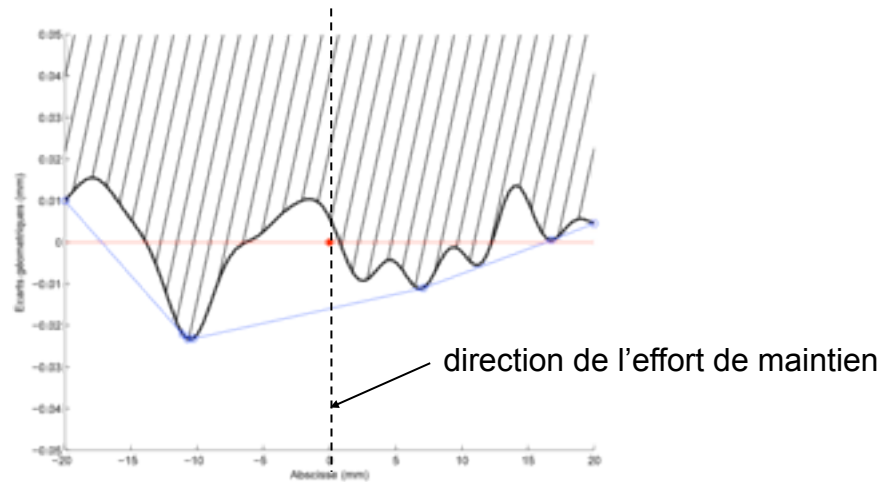
$$\lambda_{1A2_i} = \lambda_{A2_i} - \lambda_{A1_i}$$



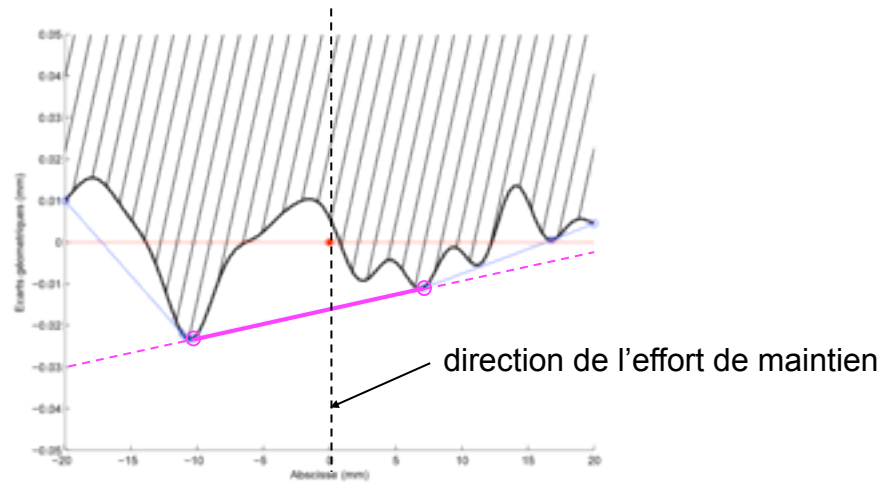
Assembly of rigid and form deviations



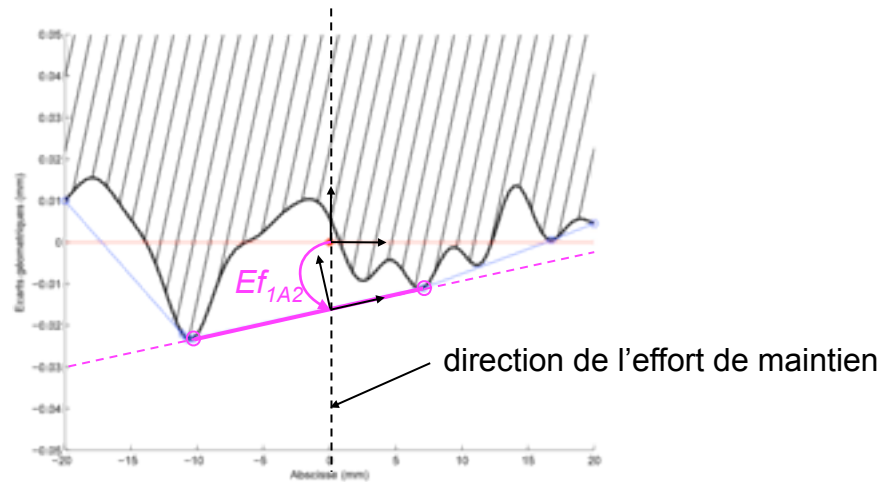
Assembly of rigid and form deviations



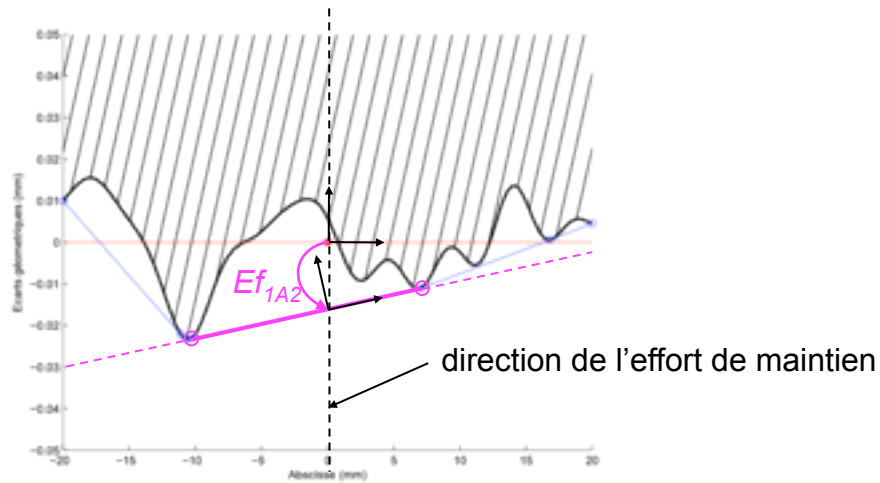
Assembly of rigid and form deviations



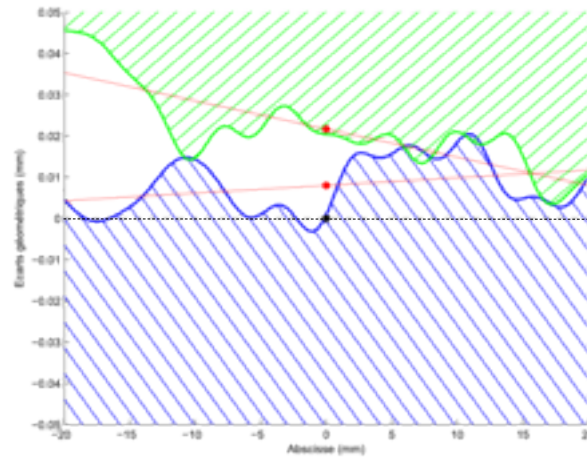
Assembly of rigid and form deviations



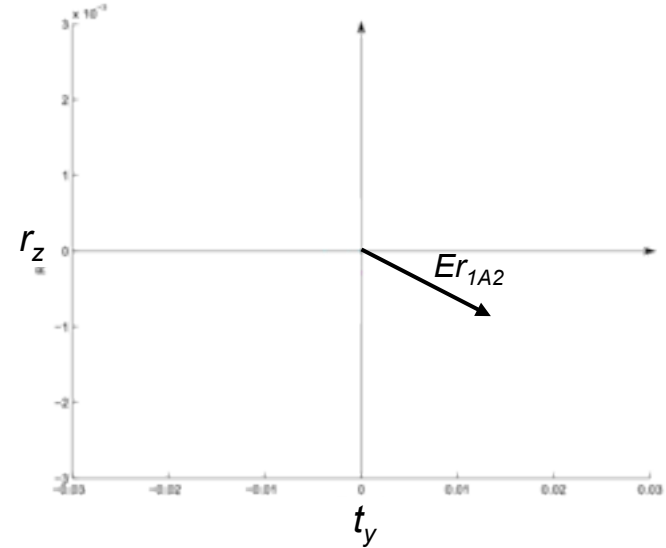
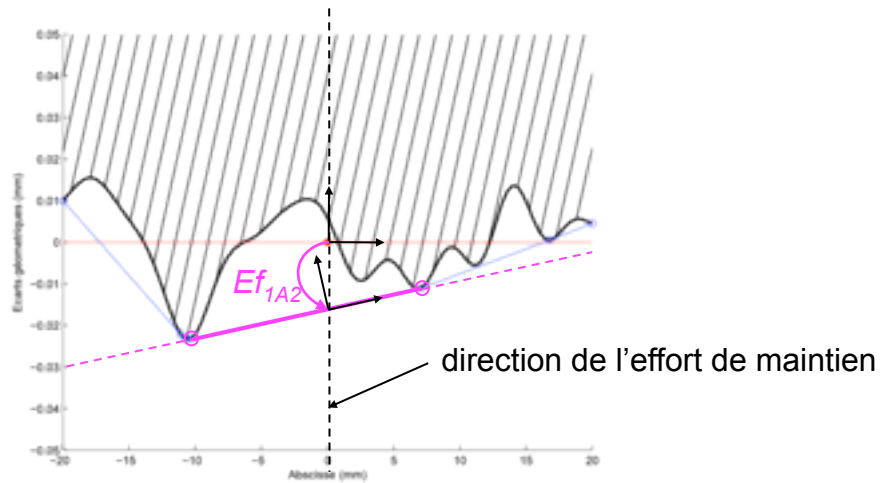
Assembly of rigid and form deviations



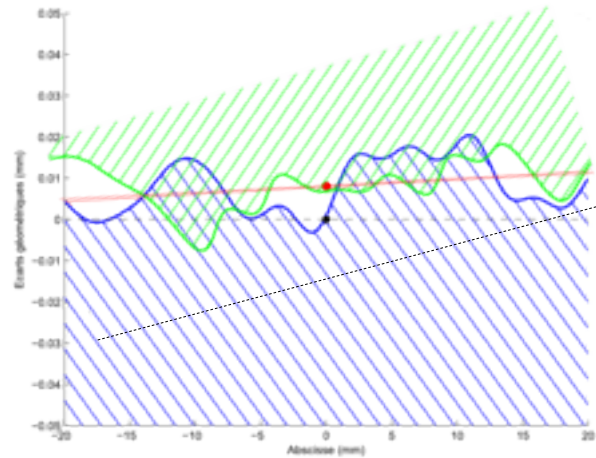
MIP sur la
facette



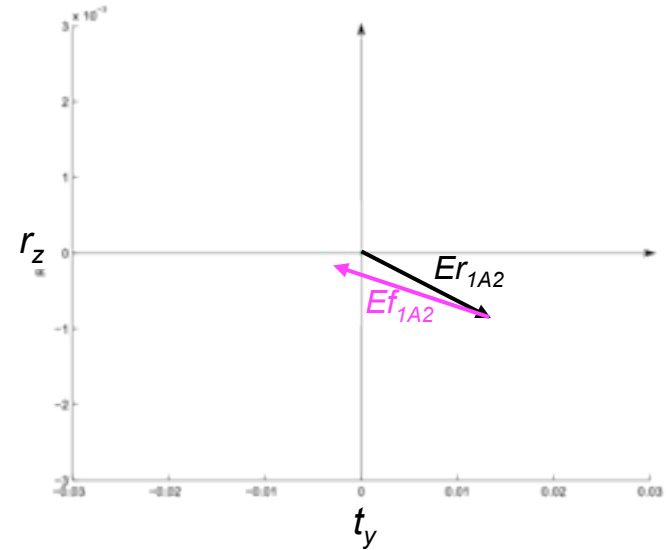
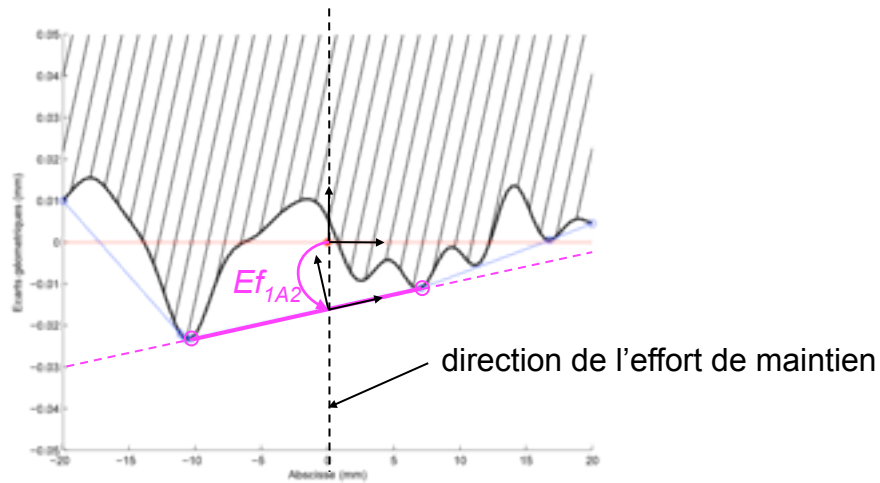
Assembly of rigid and form deviations



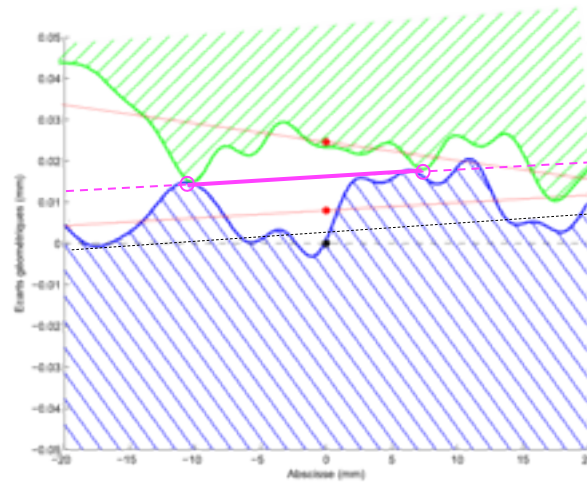
MIP sur la facette



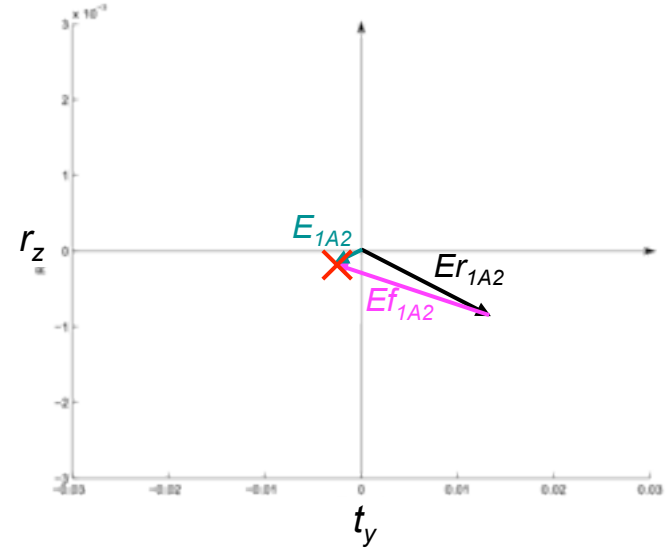
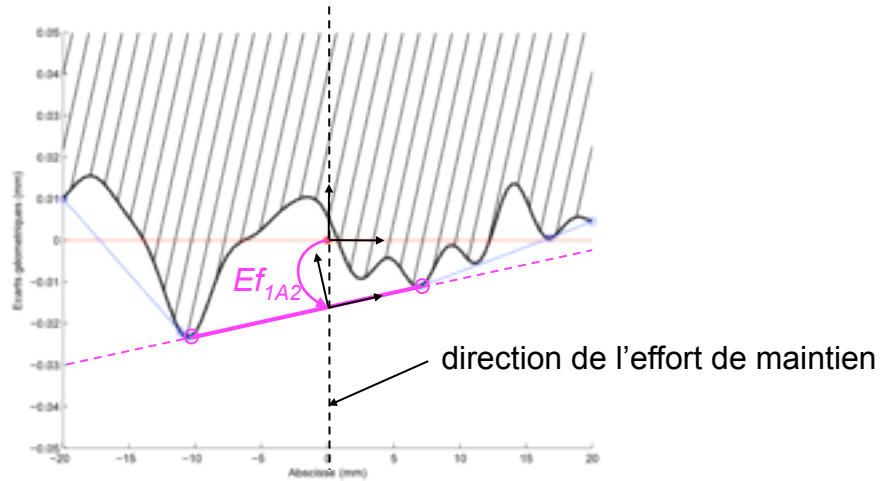
Assembly of rigid and form deviations



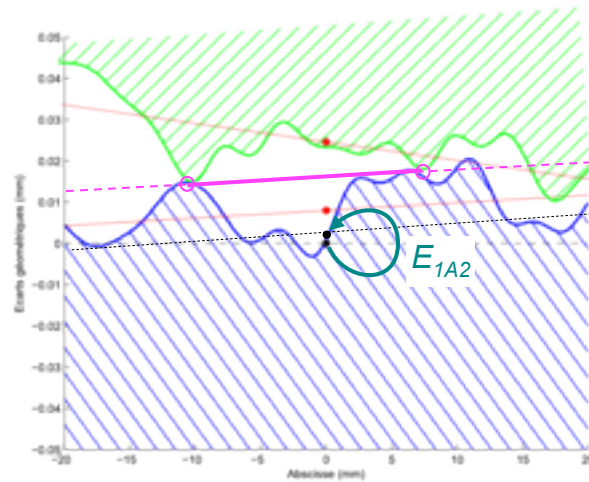
MIP sur la facette



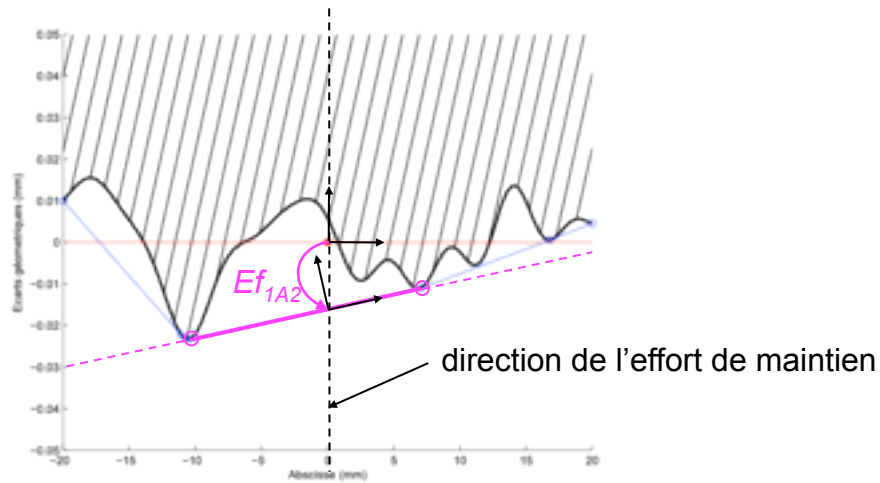
Assembly of rigid and form deviations



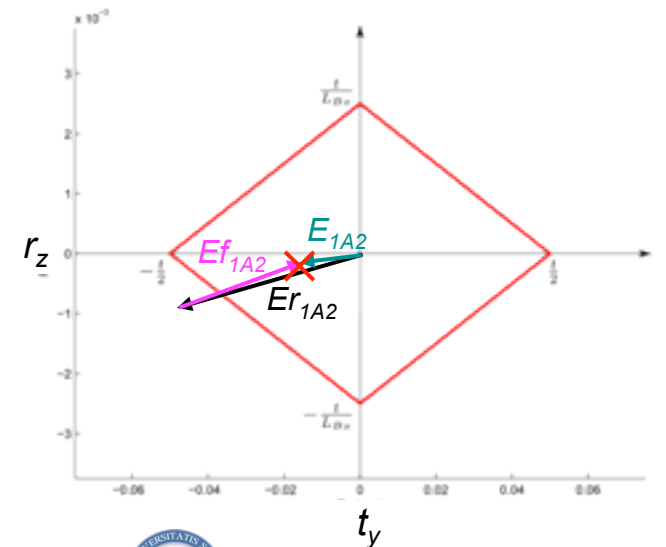
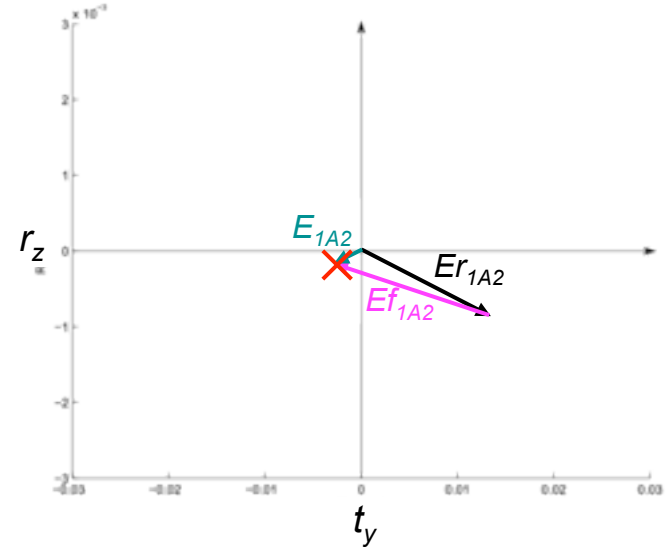
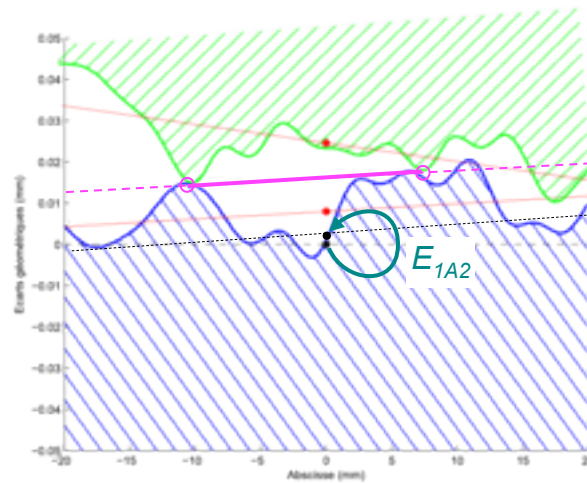
MIP sur la facette



Assembly of rigid and form deviations



MIP sur la facette

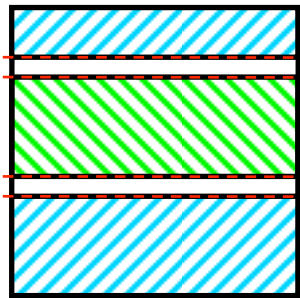




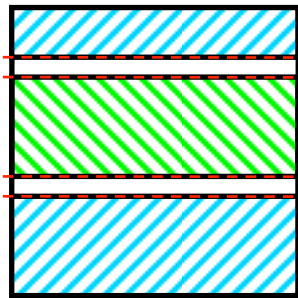
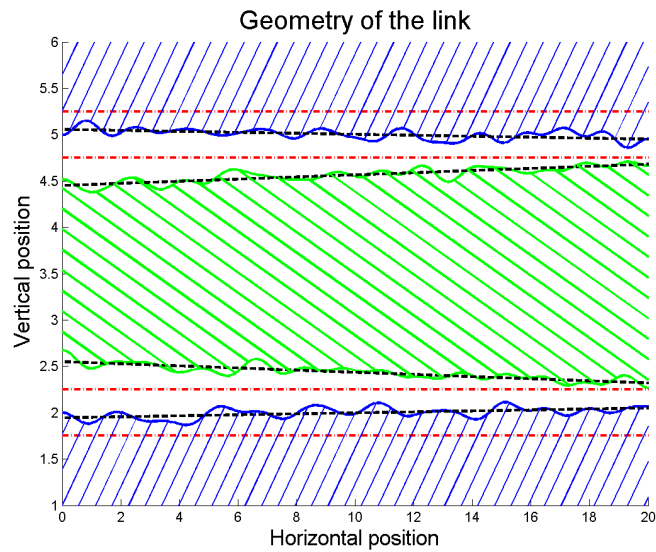
Influence of form deviations in clearance linkage

Clearance and form deviations

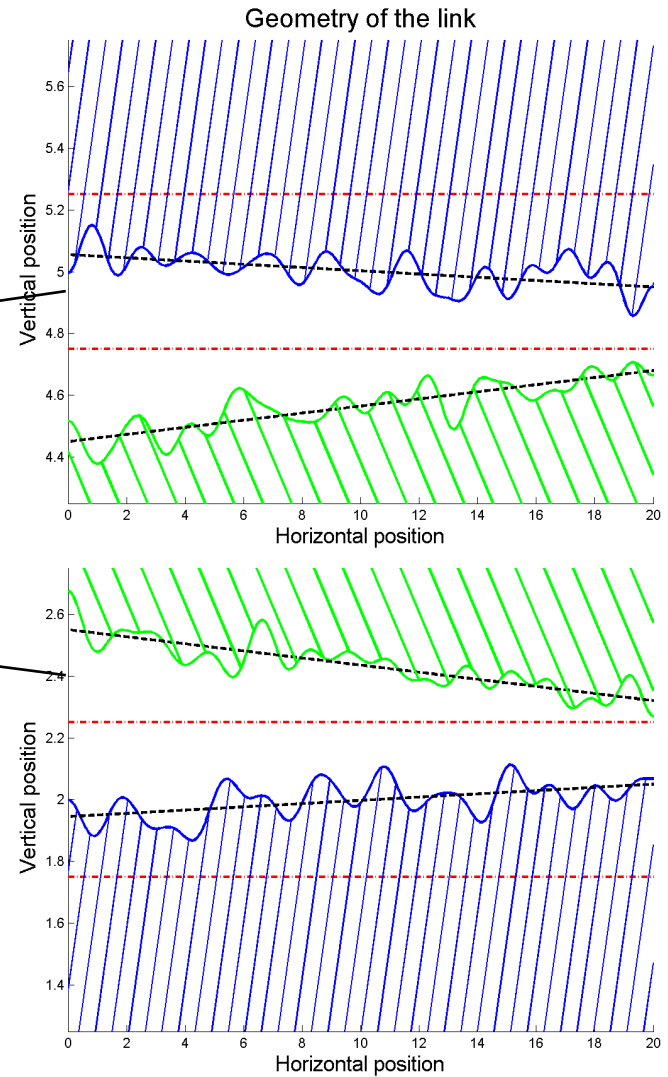
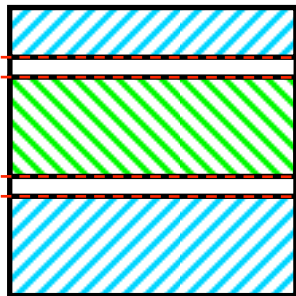
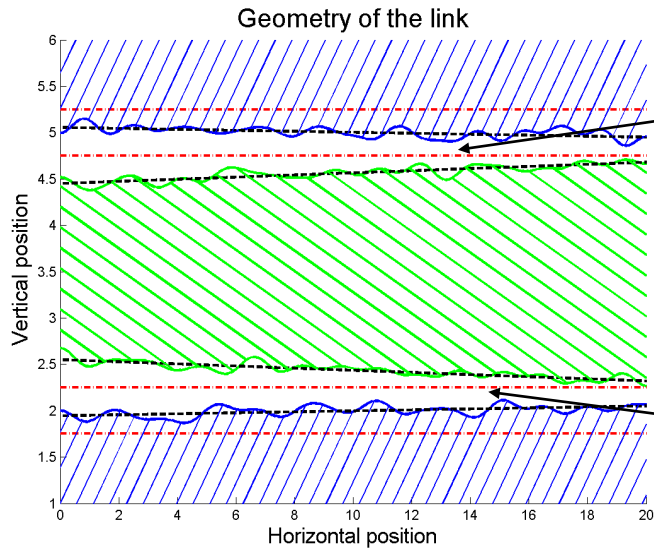
Clearance and form deviations



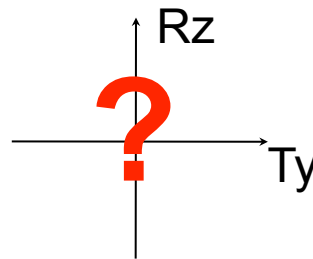
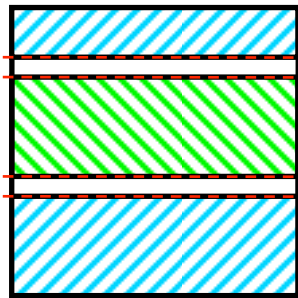
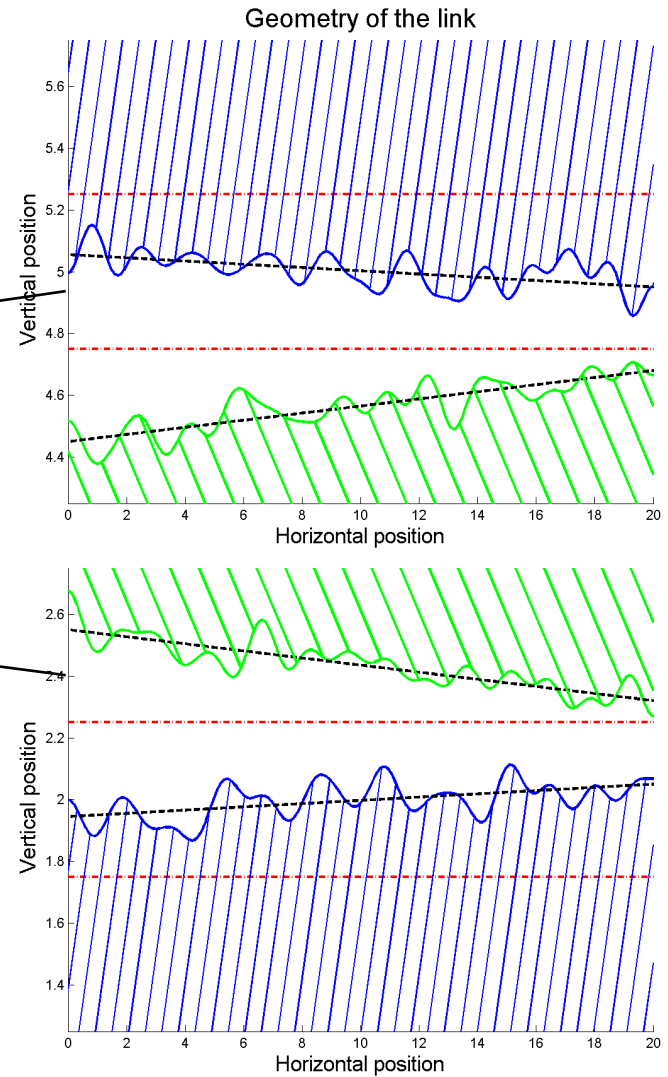
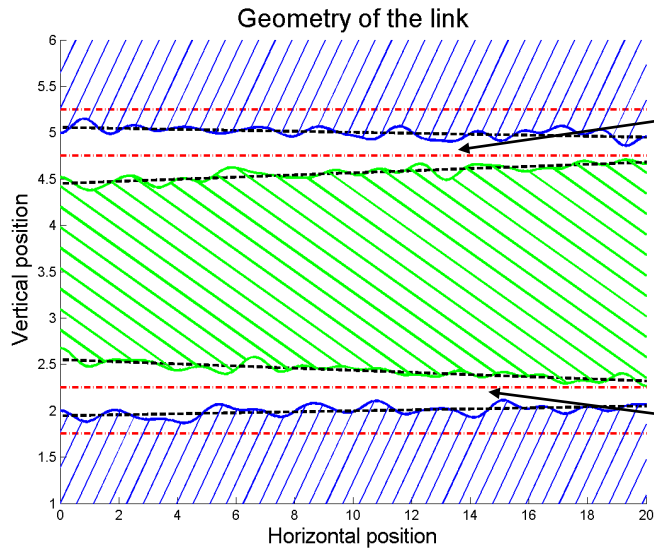
Clearance and form deviations



Clearance and form deviations

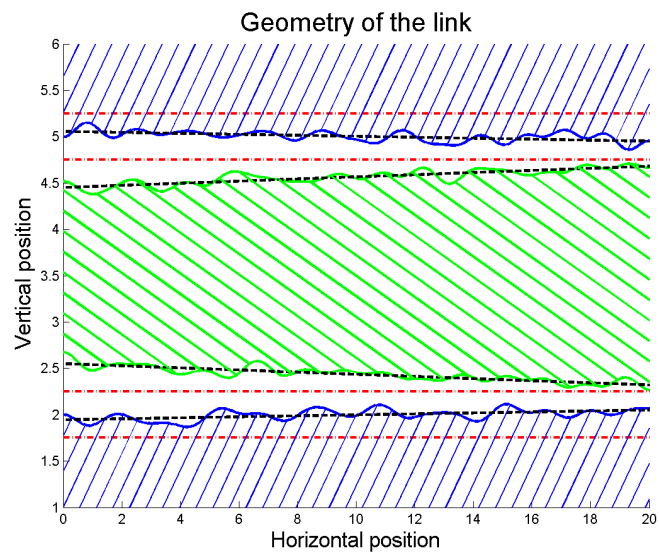


Clearance and form deviations

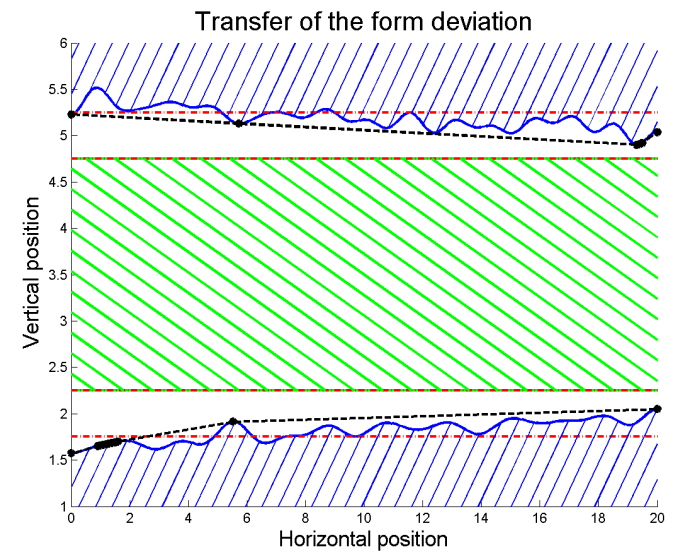
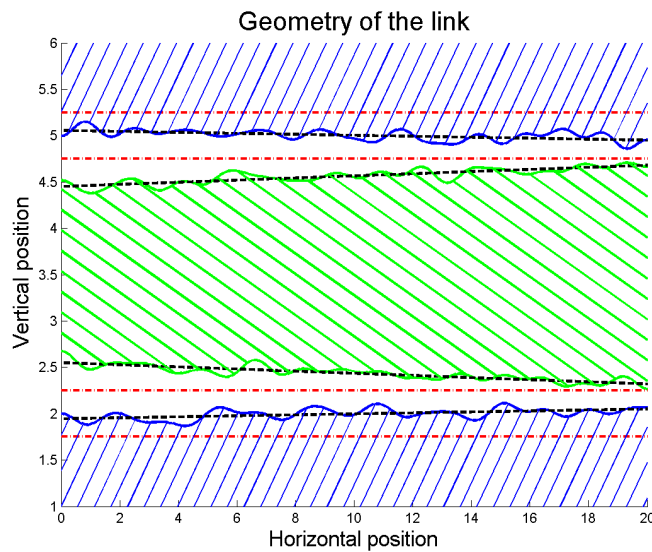


Clearance and form deviations

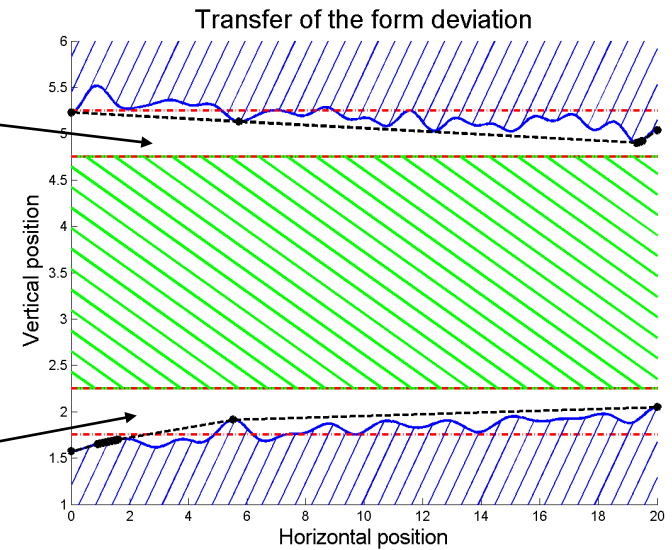
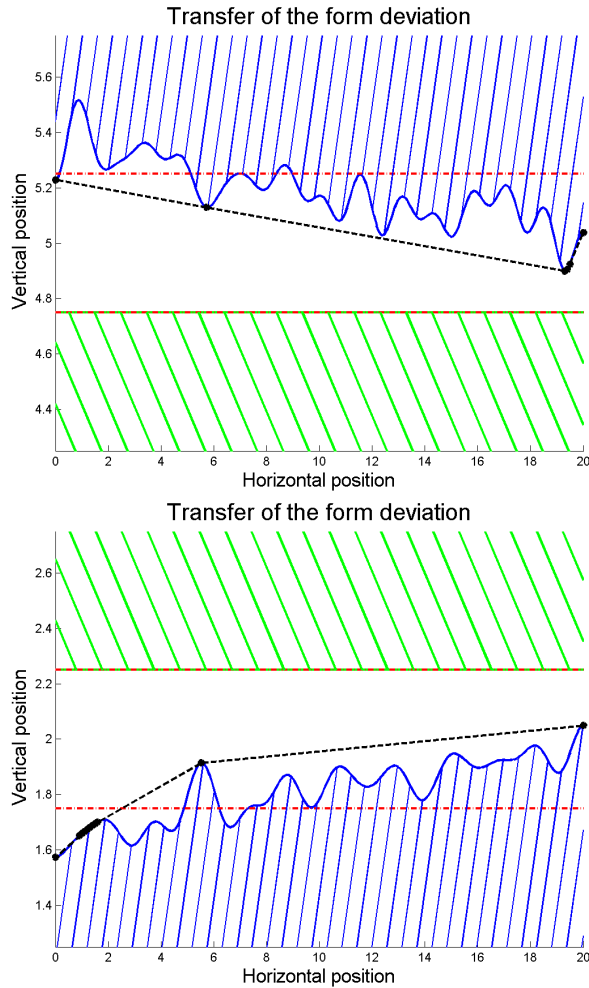
Clearance and form deviations



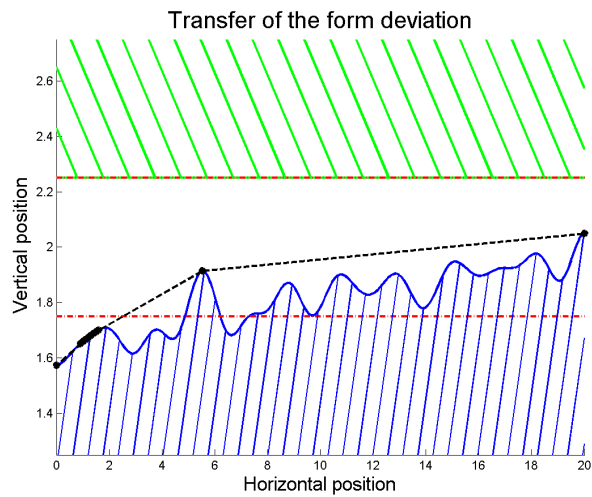
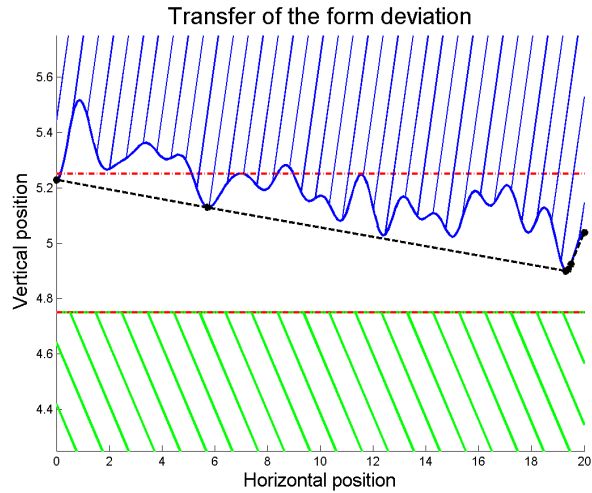
Clearance and form deviations



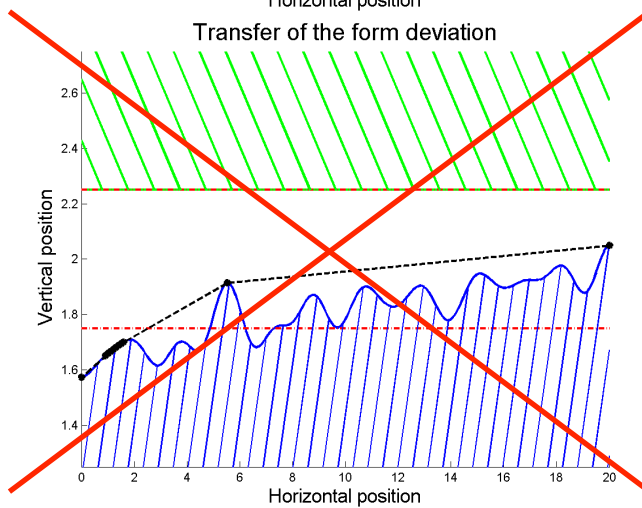
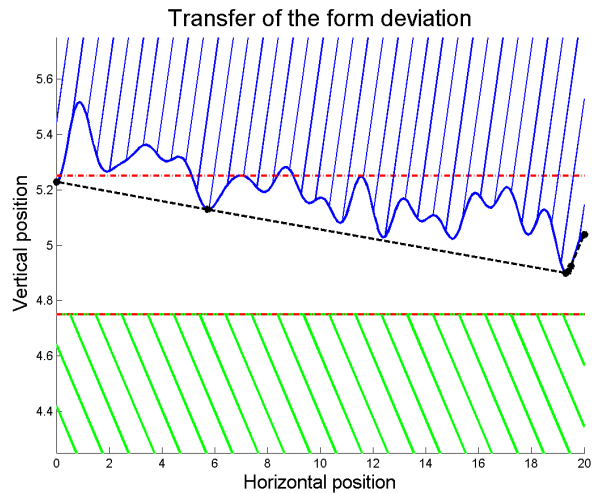
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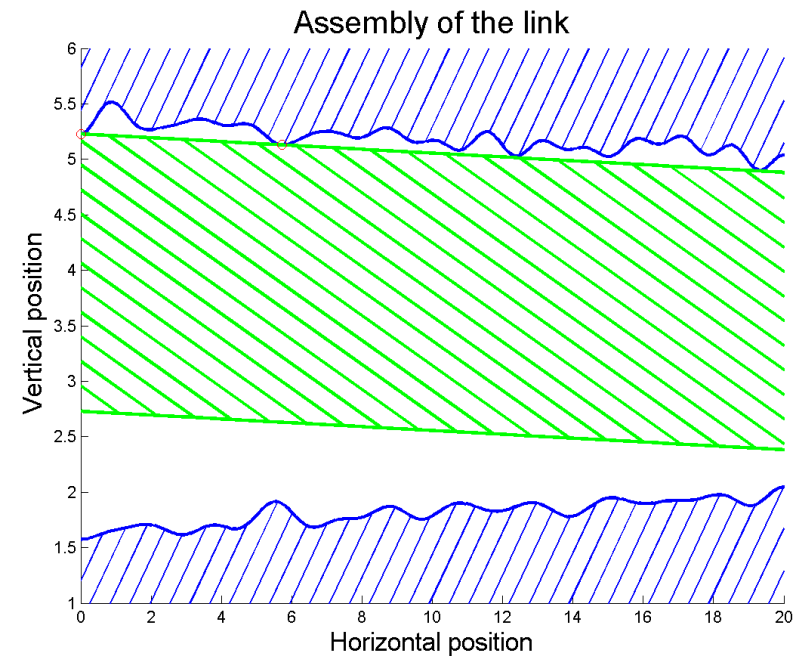
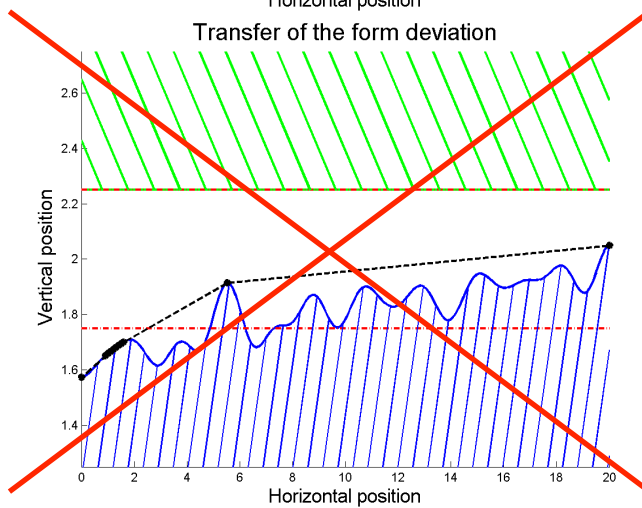
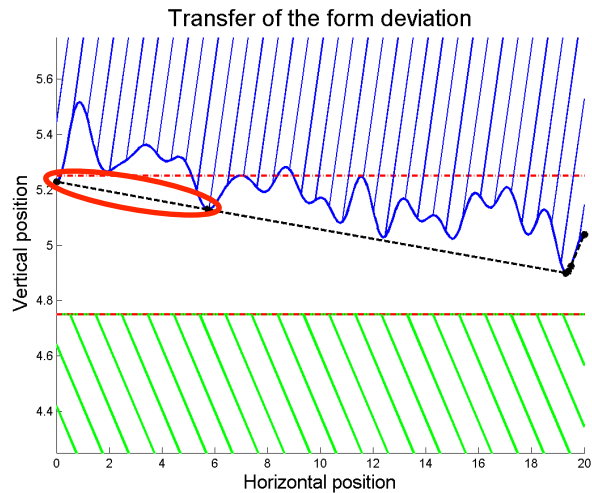
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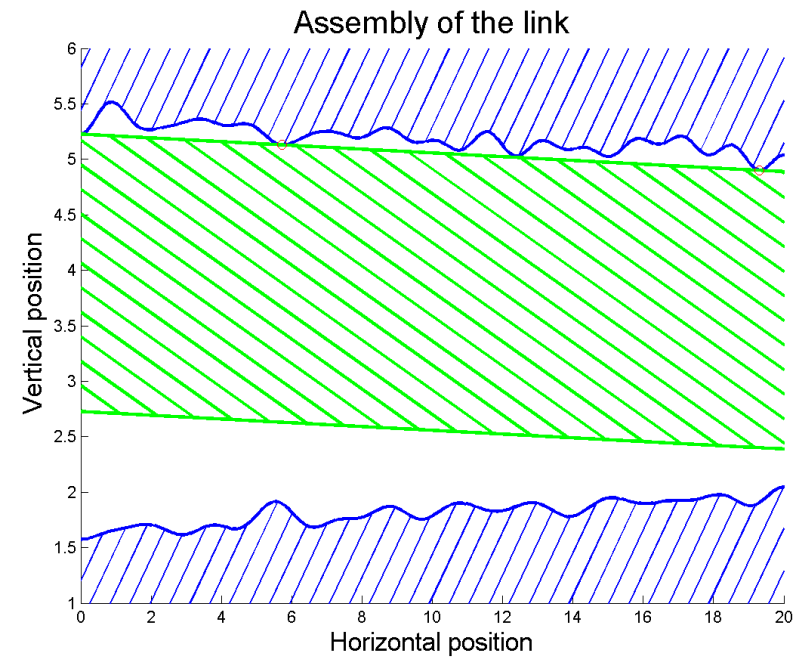
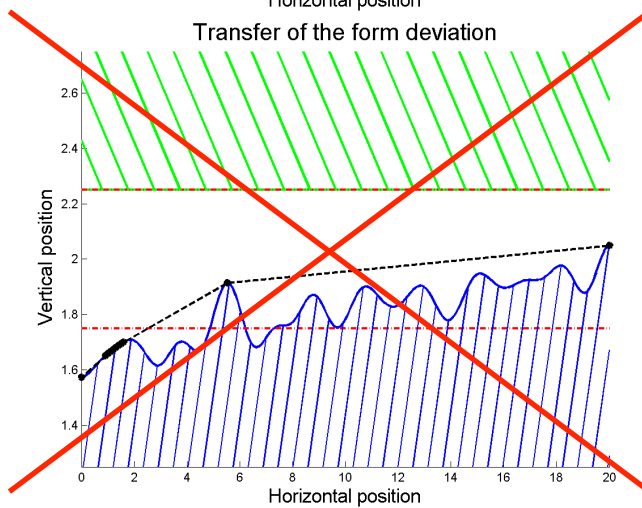
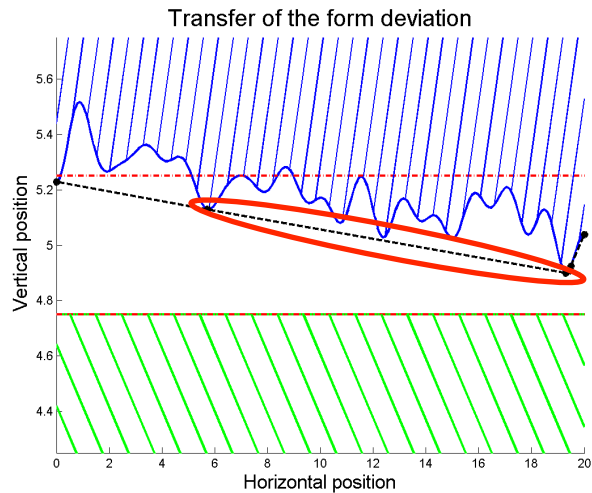
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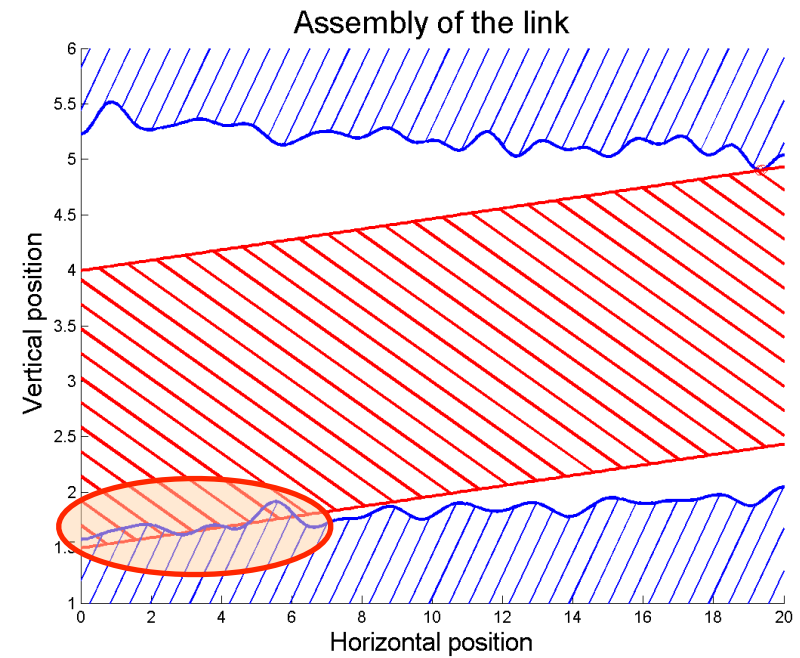
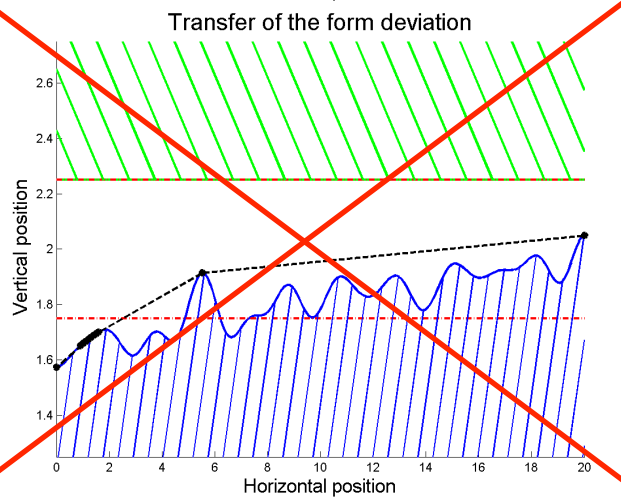
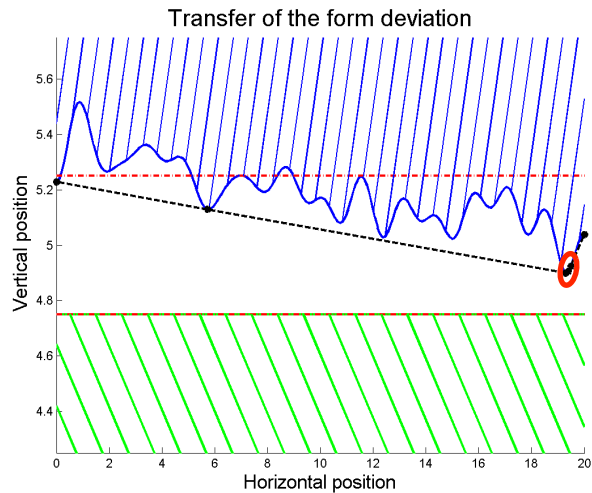
Clearance and form deviations



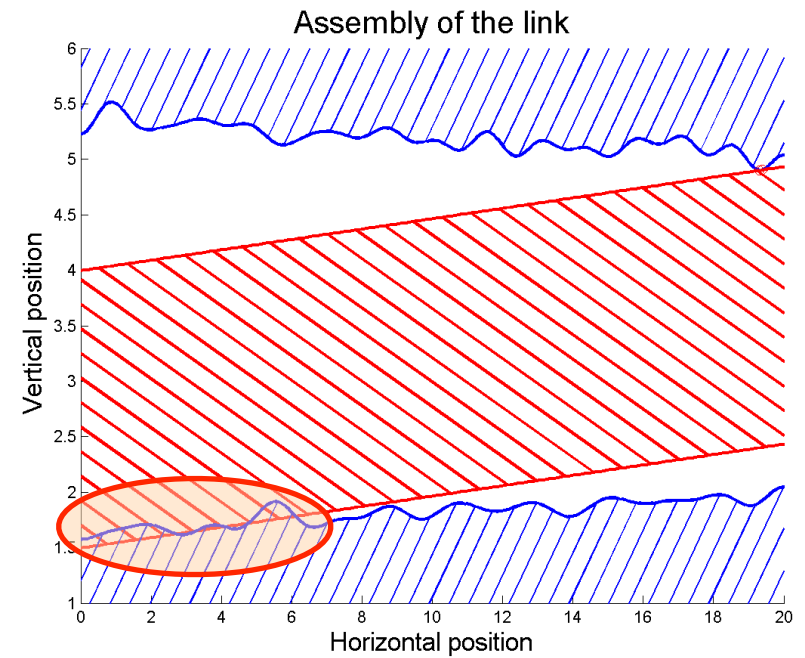
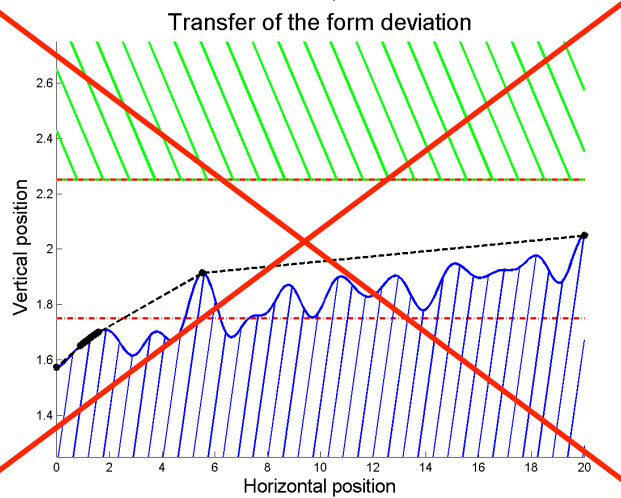
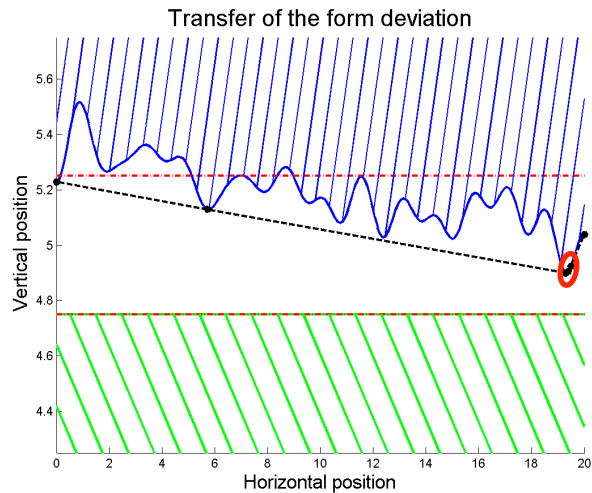
Clearance and form deviations



Clearance and form deviations

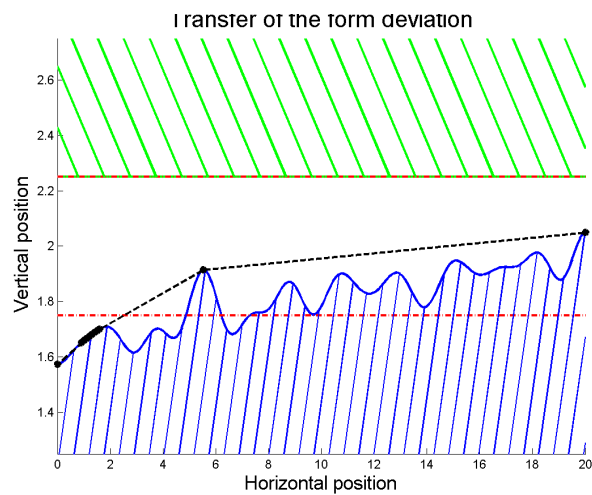
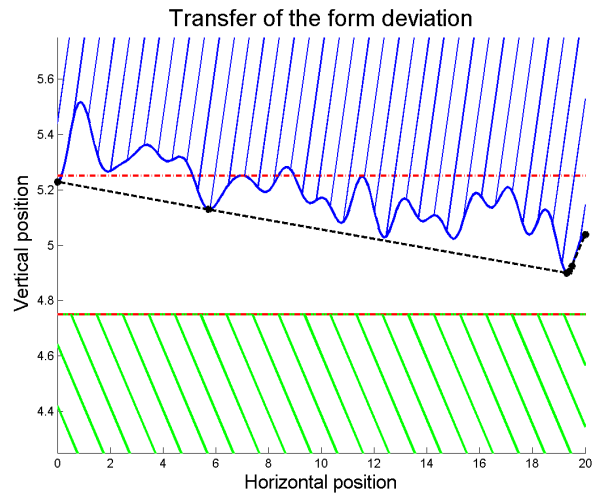


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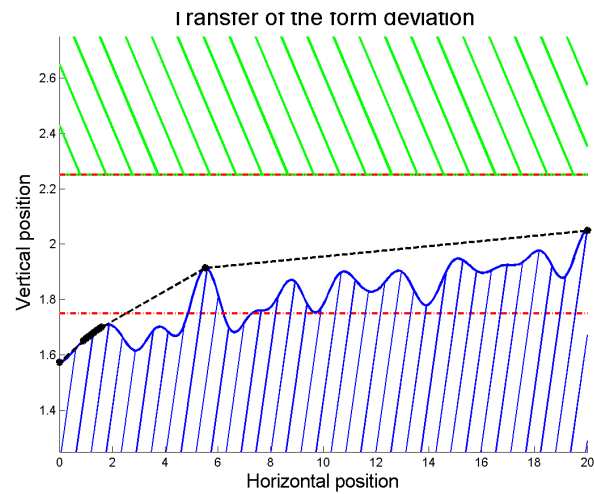
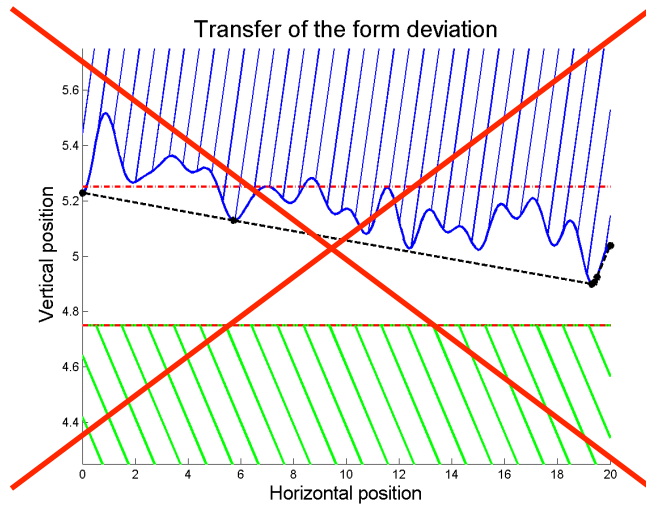


2 positioning

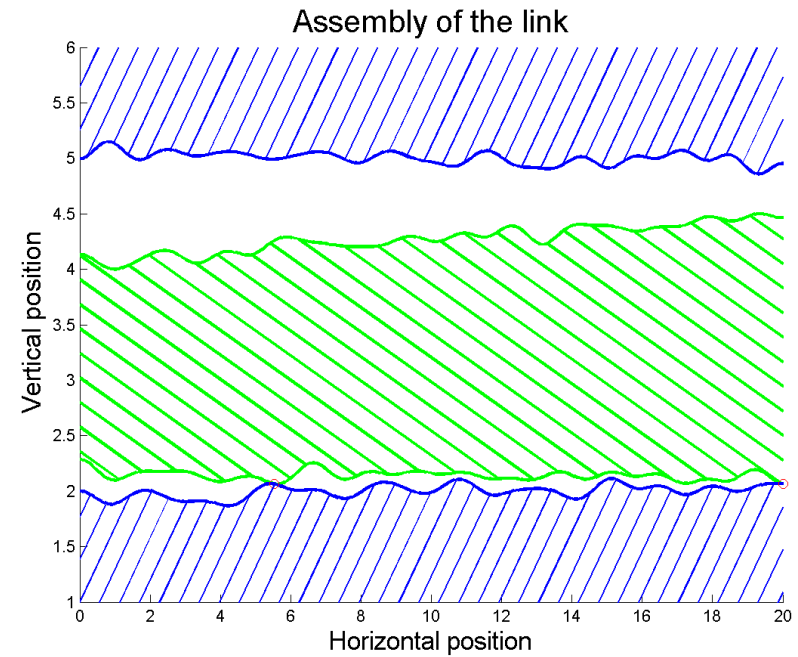
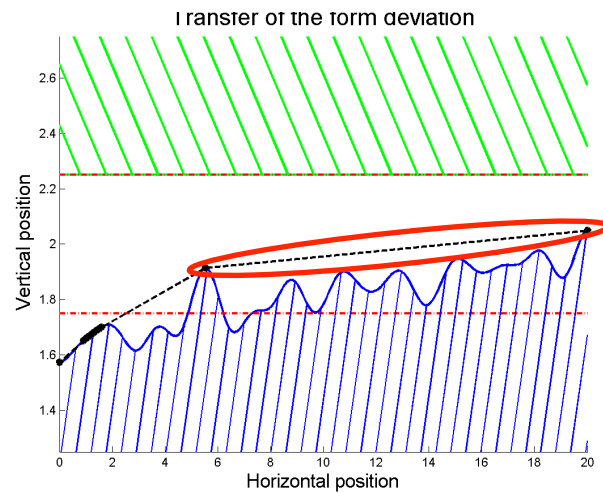
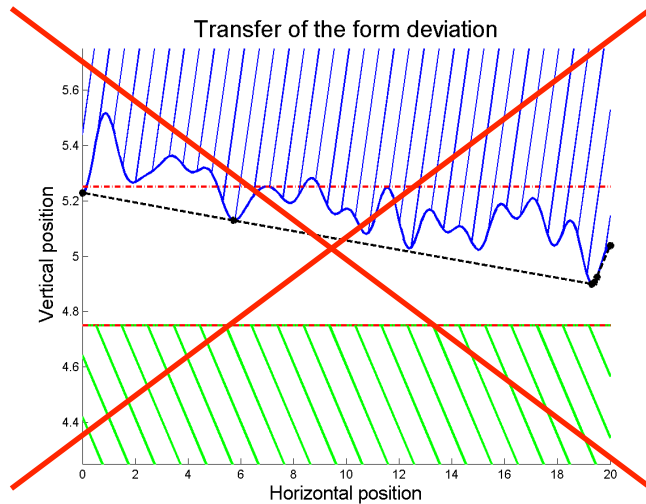
Clearance and form deviations



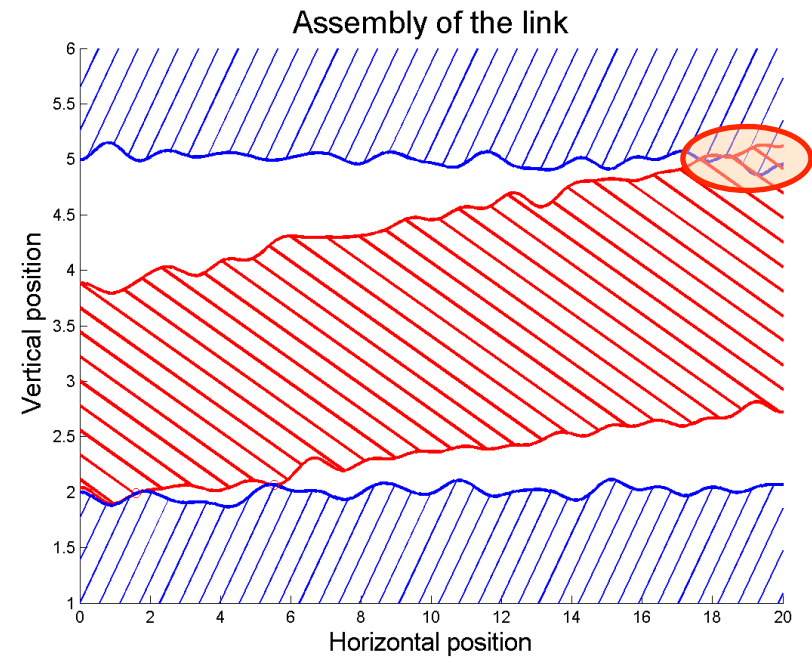
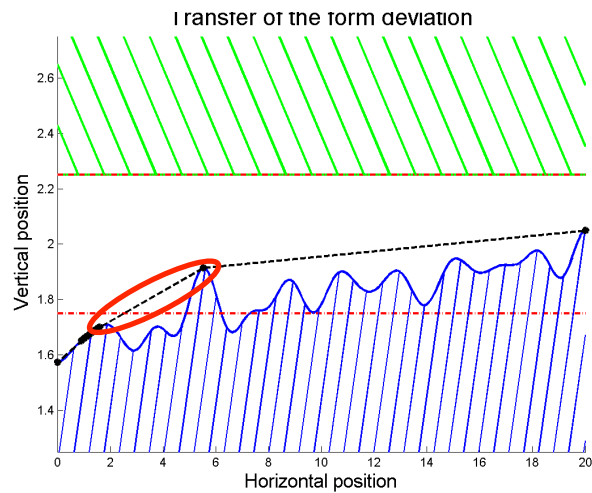
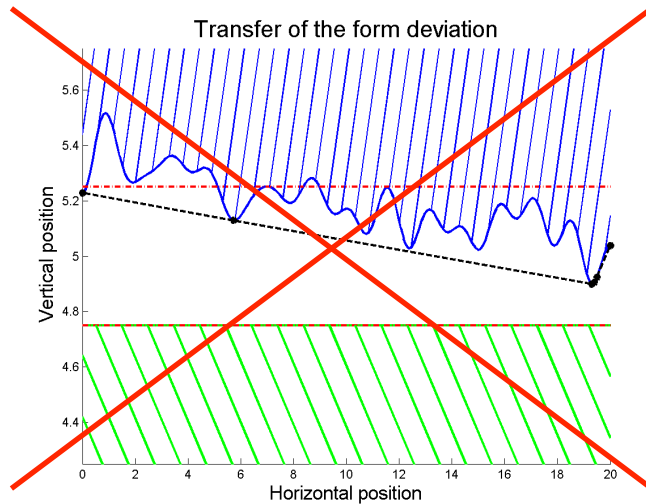
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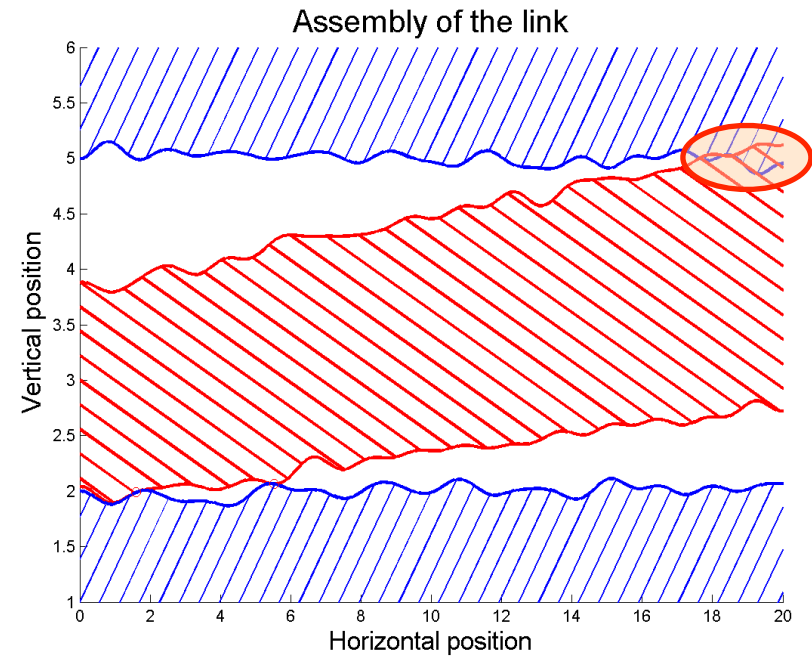
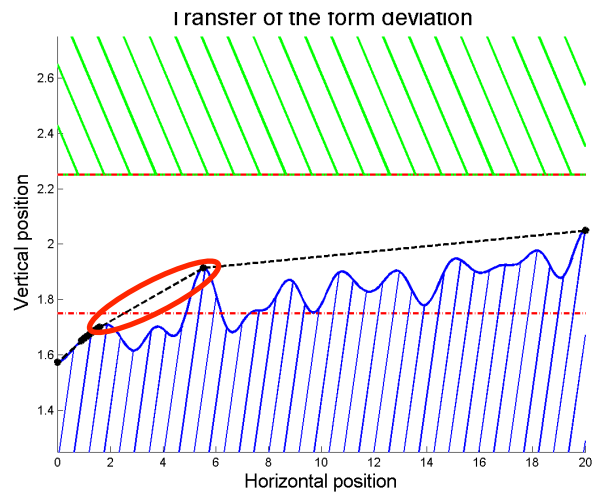
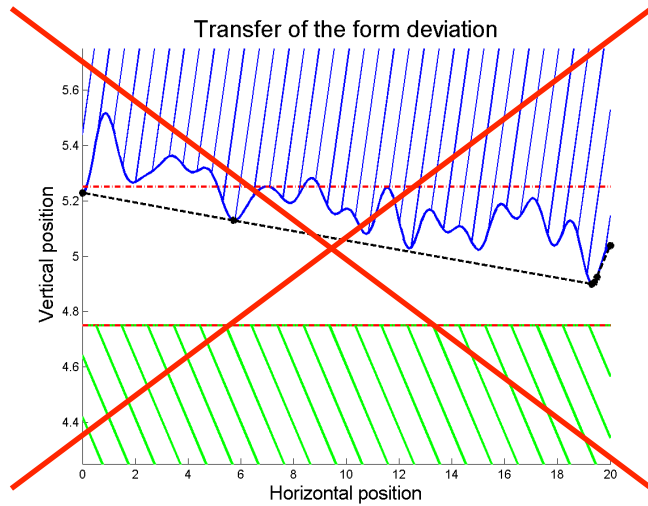
Clearance and form deviations



Clearance and form deviations



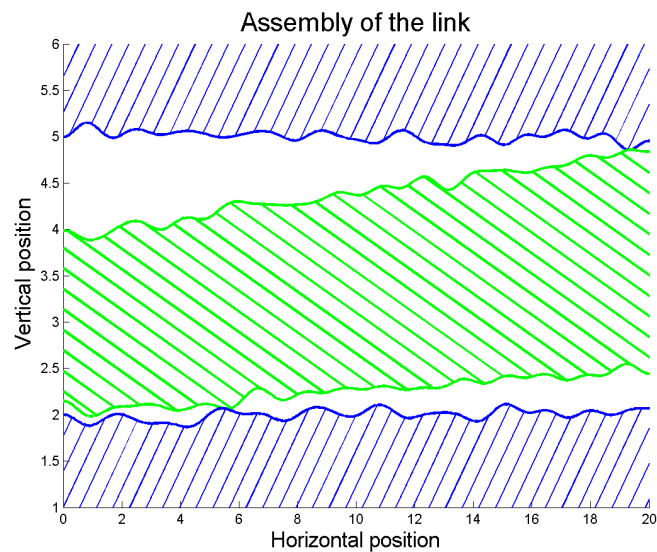
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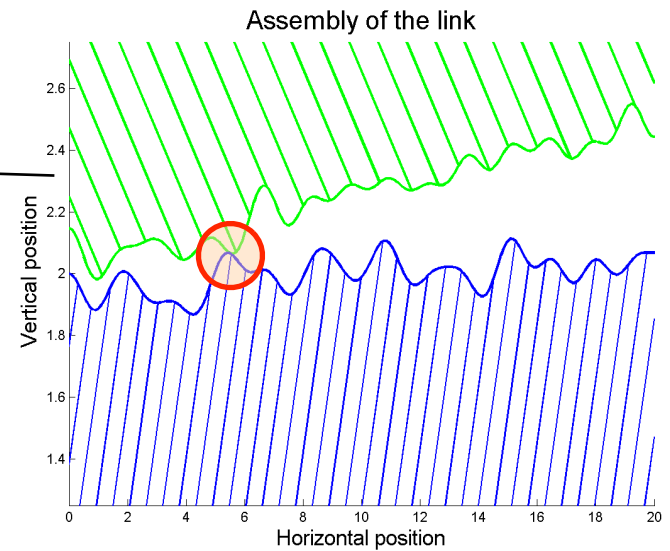
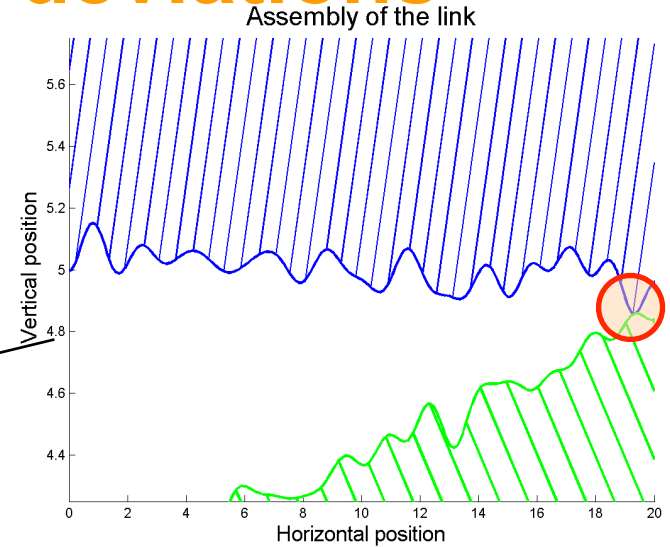
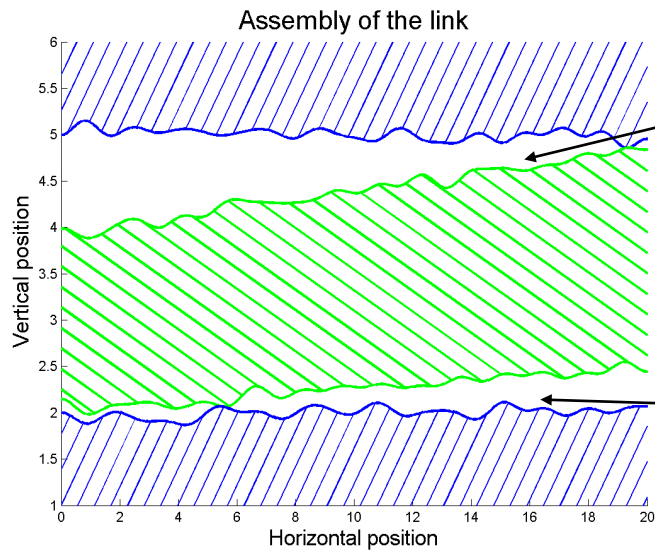
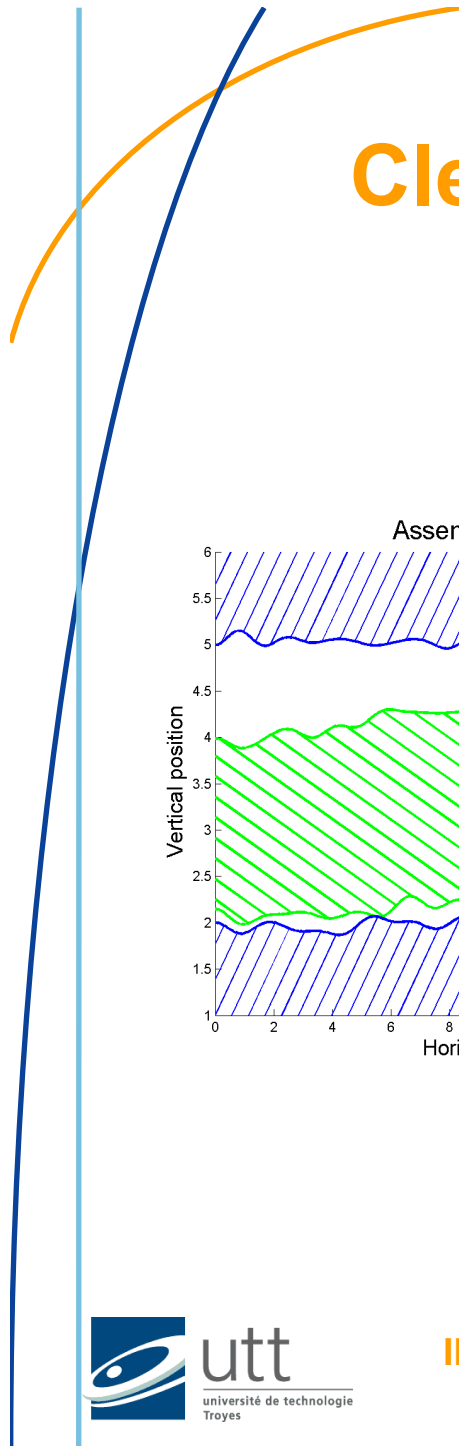
1 positioning

Clearance and form deviations

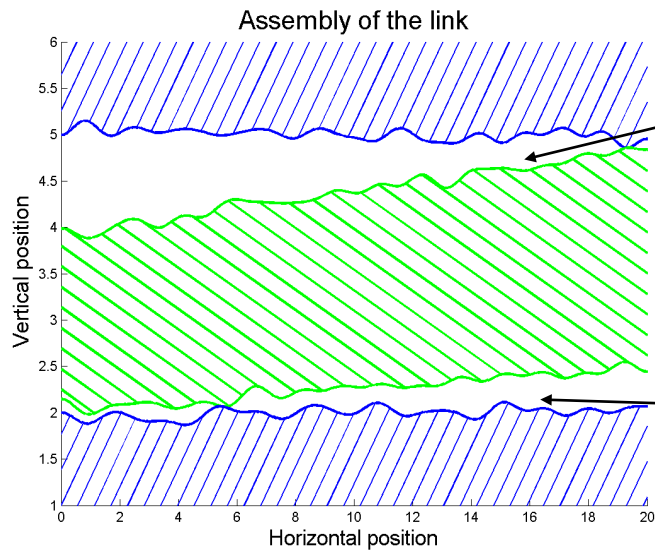
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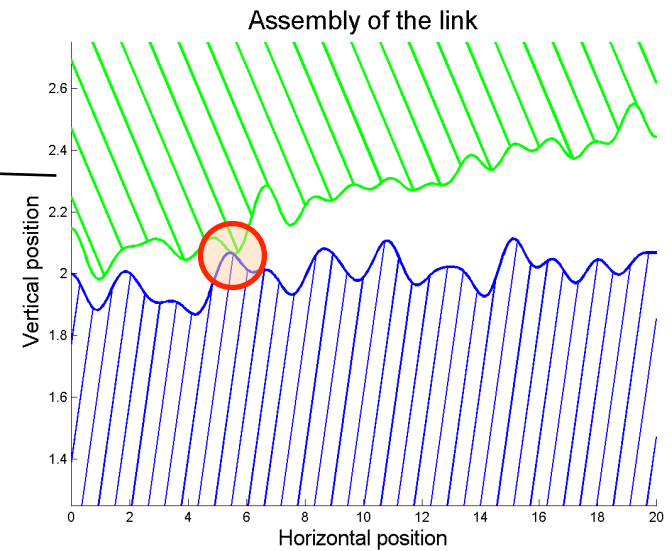
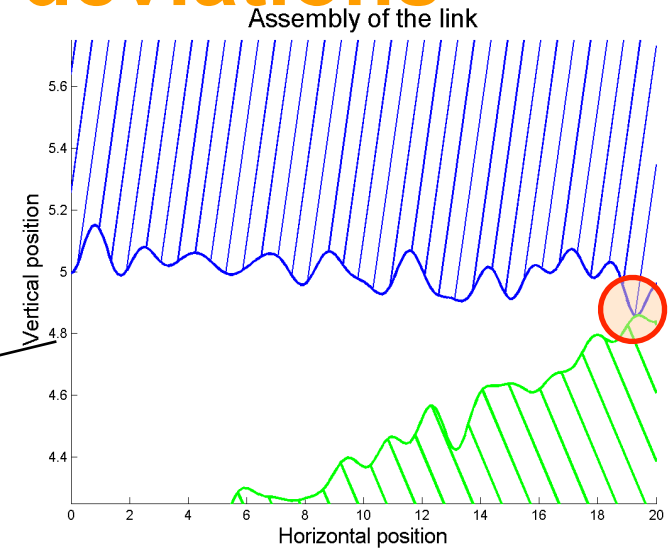
Clearance and form deviations



Clearance and form deviations



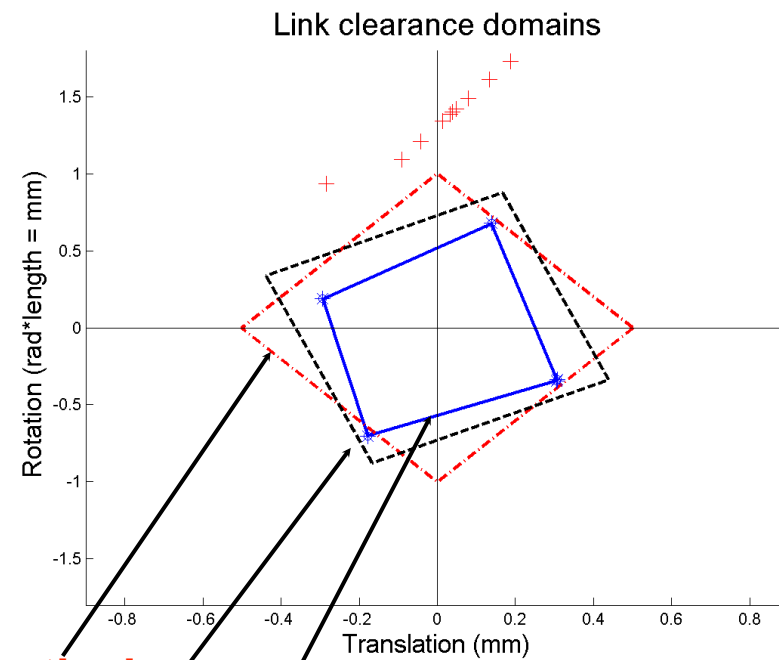
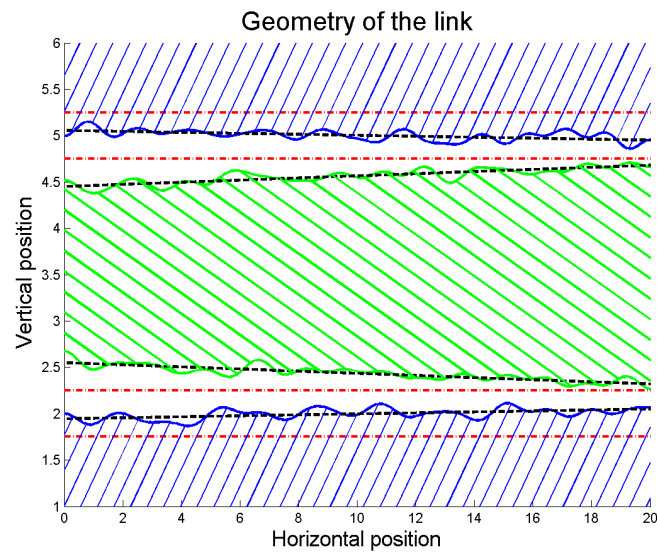
2 MIP





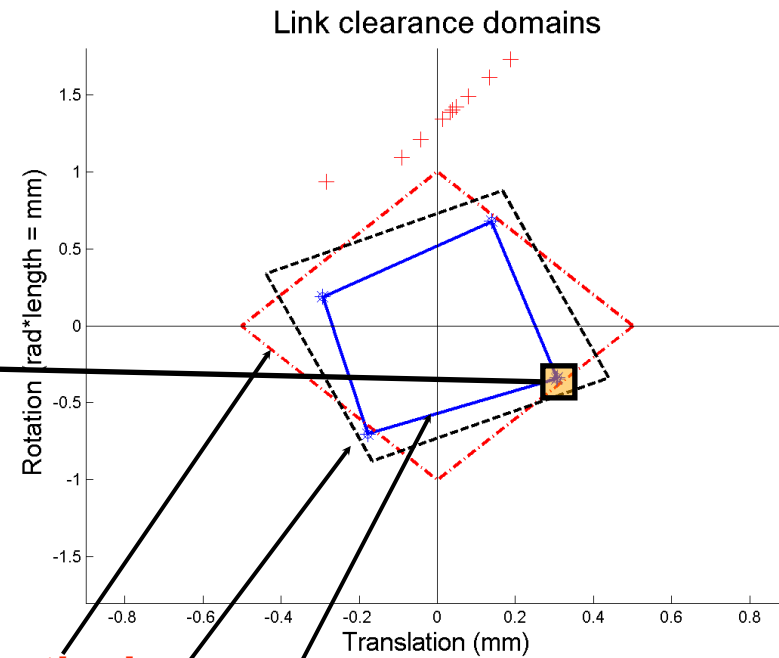
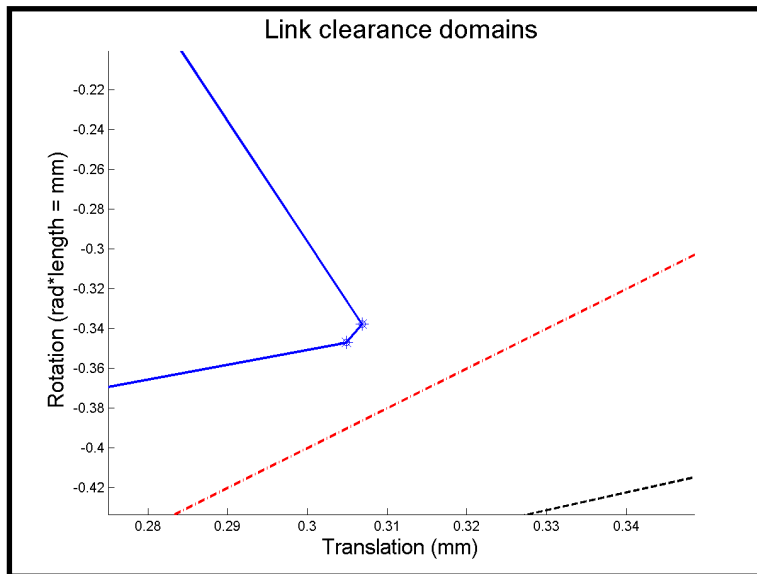
Clearance and form deviations

Clearance and form deviations



Theoretical
Rigid
Rigid + Form

Clearance and form deviations

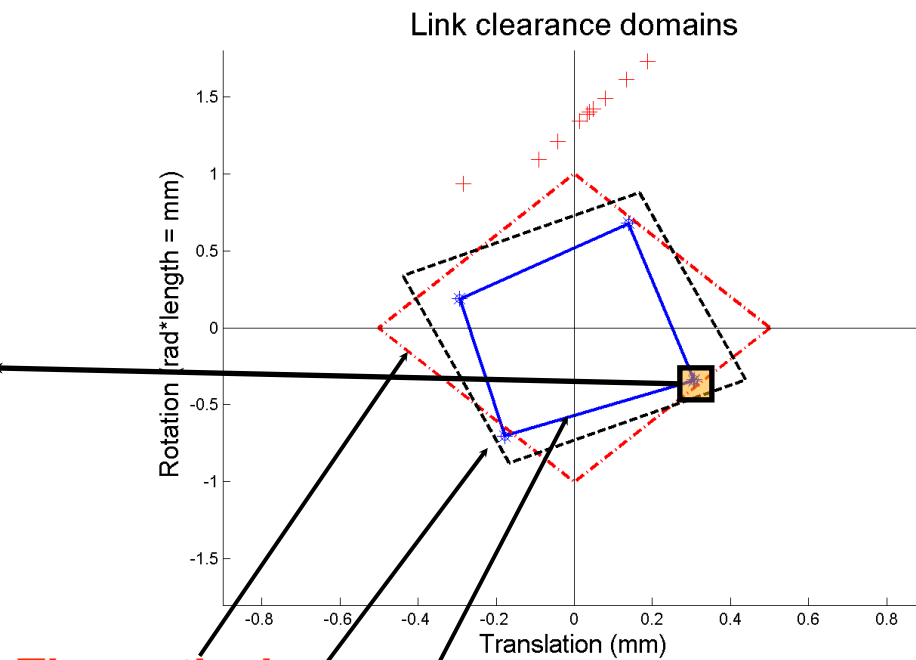
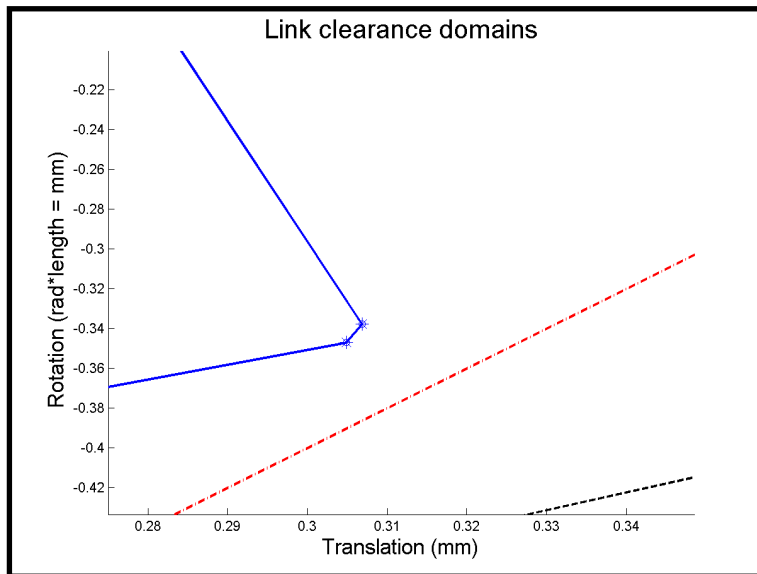


Theoretical

Rigid

Rigid + Form

Clearance and form deviations



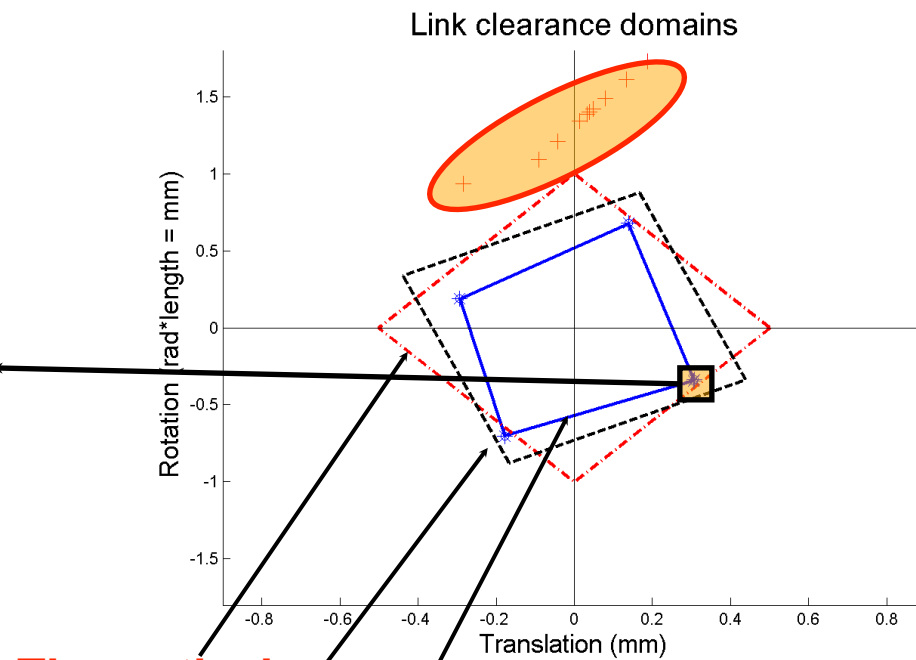
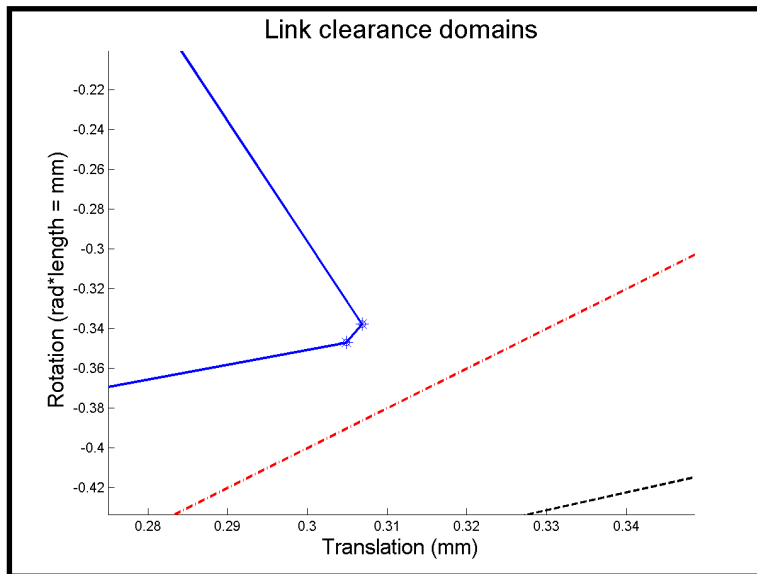
Total : 5 contact configurations

Theoretical

Rigid

Rigid + Form

Clearance and form deviations



Total : 5 contact configurations

Theoretical

Rigid

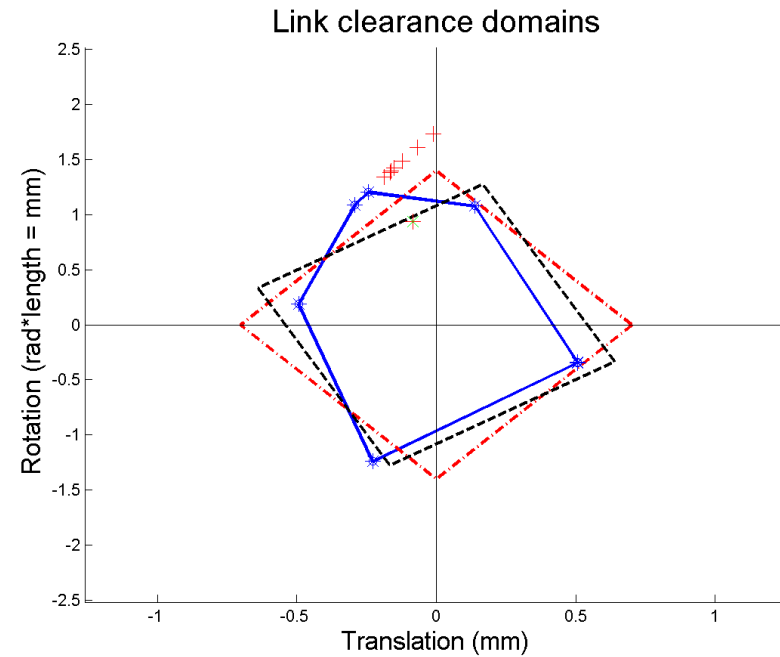
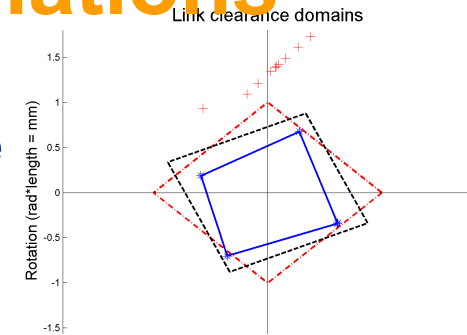
Rigid + Form

Clearance and form deviations

- Same form deviation with larger clearance

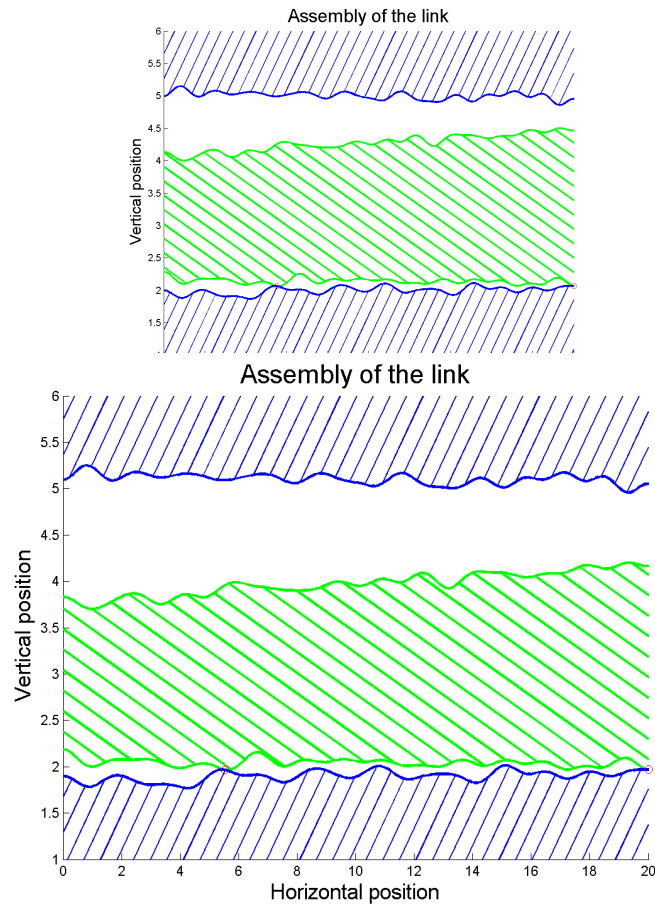
Clearance and form deviations

- Same form deviation with larger clearance

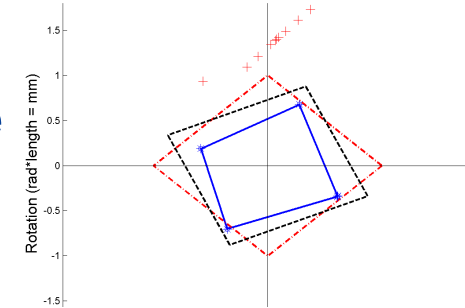


Clearance and form deviations

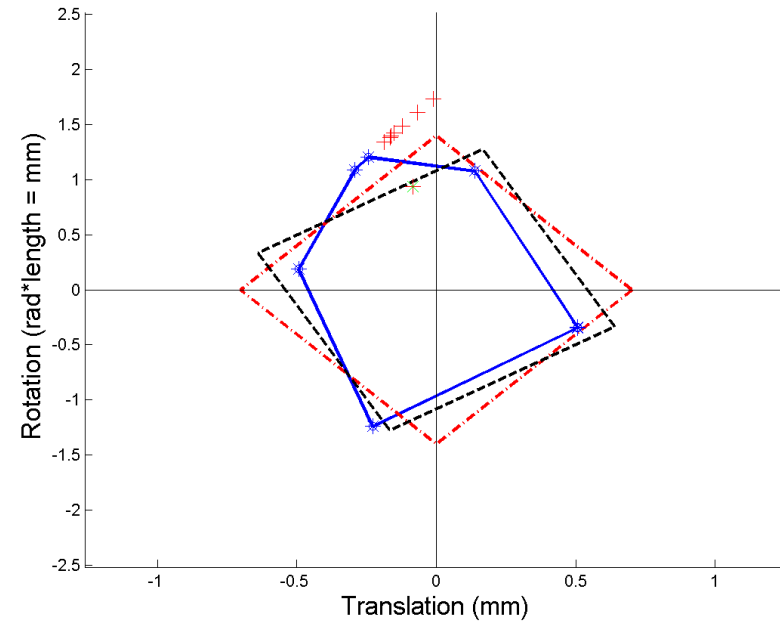
- Same form deviation with larger clearance



Link clearance domains

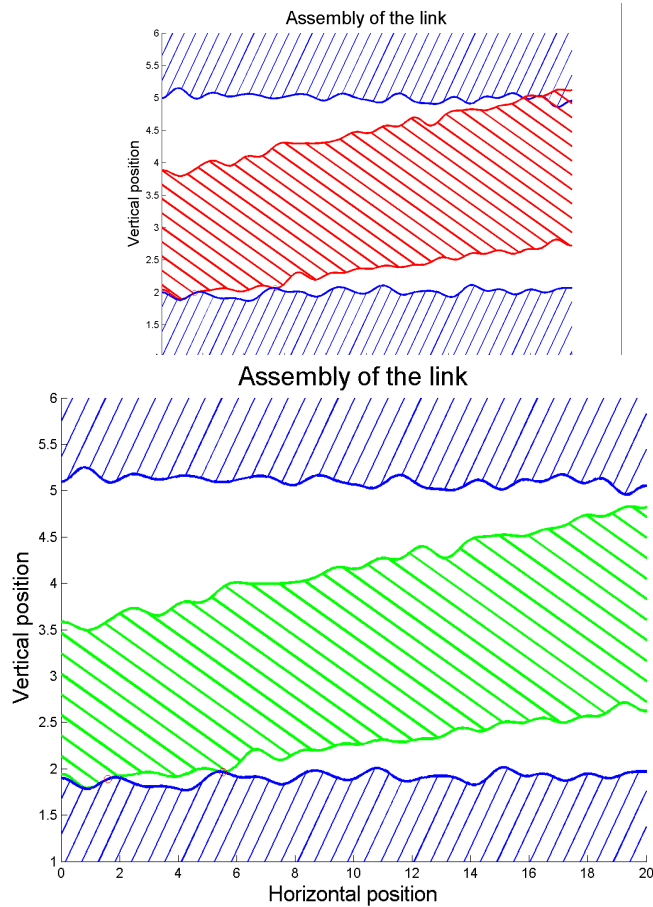


Link clearance domains

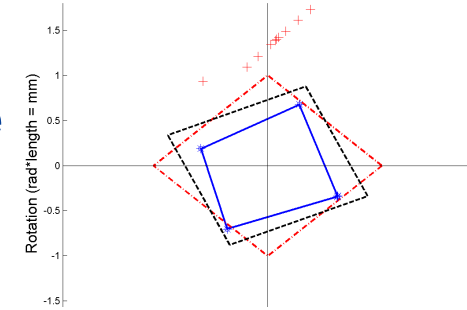


Clearance and form deviations

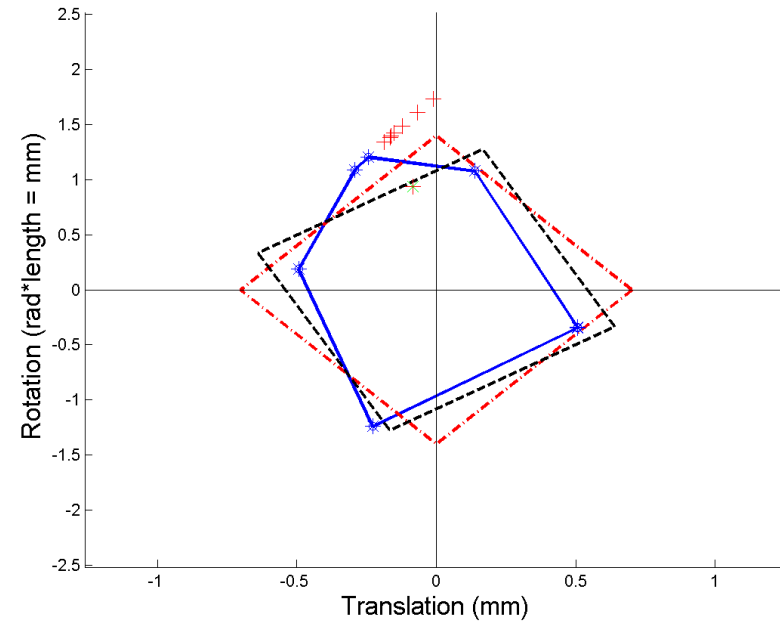
- Same form deviation with larger clearance



Link clearance domains

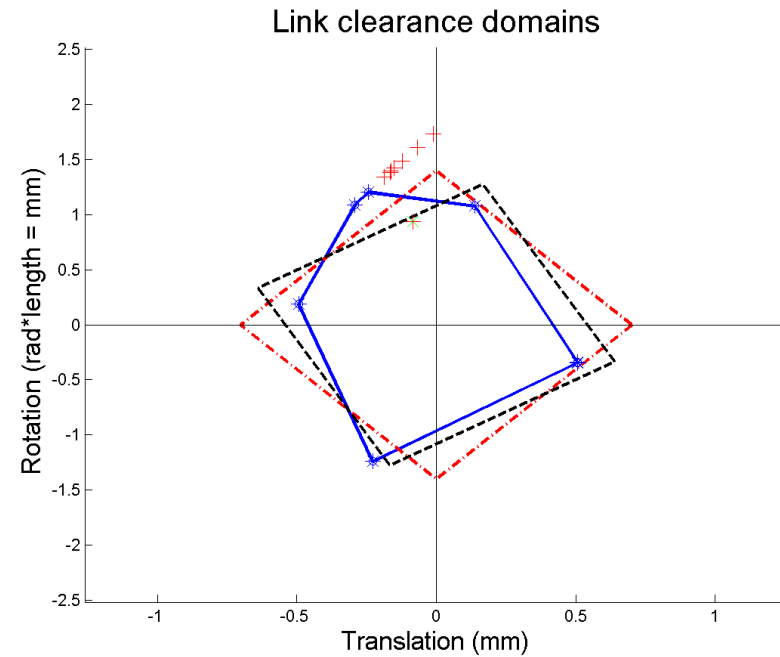
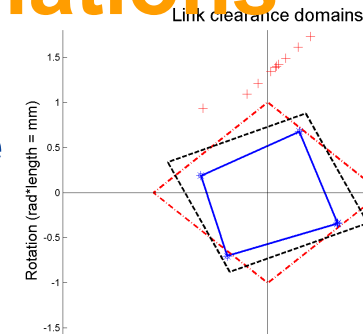
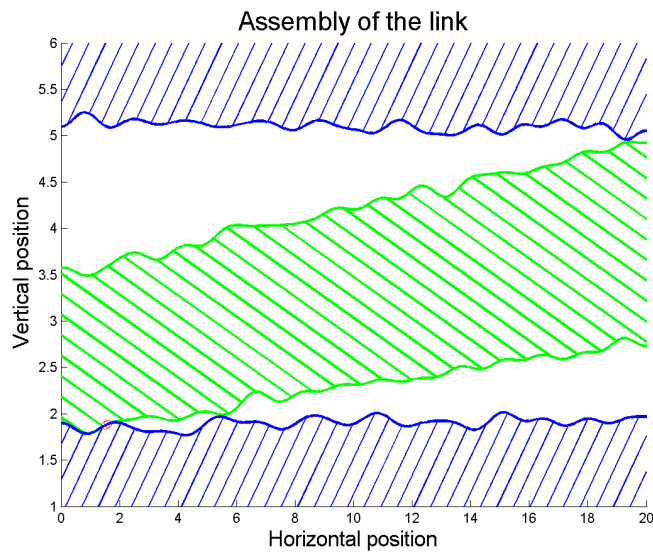


Link clearance domains



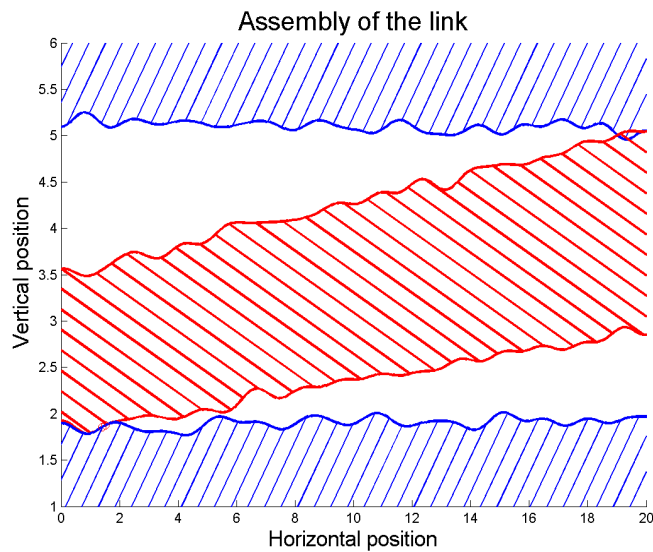
Clearance and form deviations

- Same form deviation with larger clearance

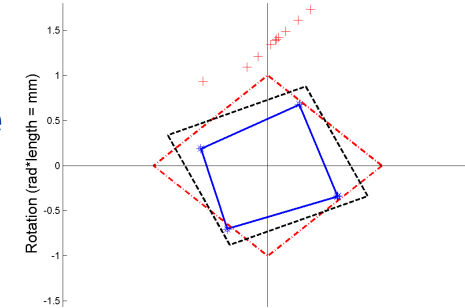


Clearance and form deviations

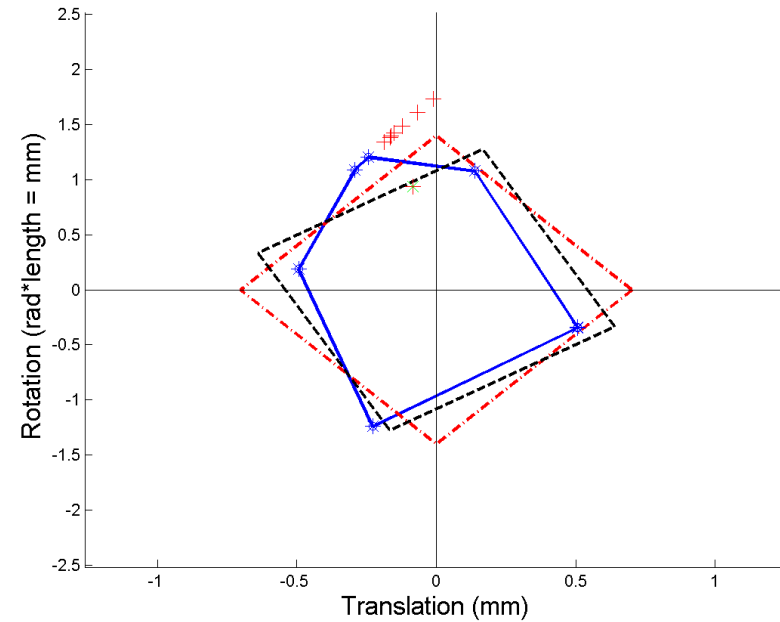
- Same form deviation with larger clearance



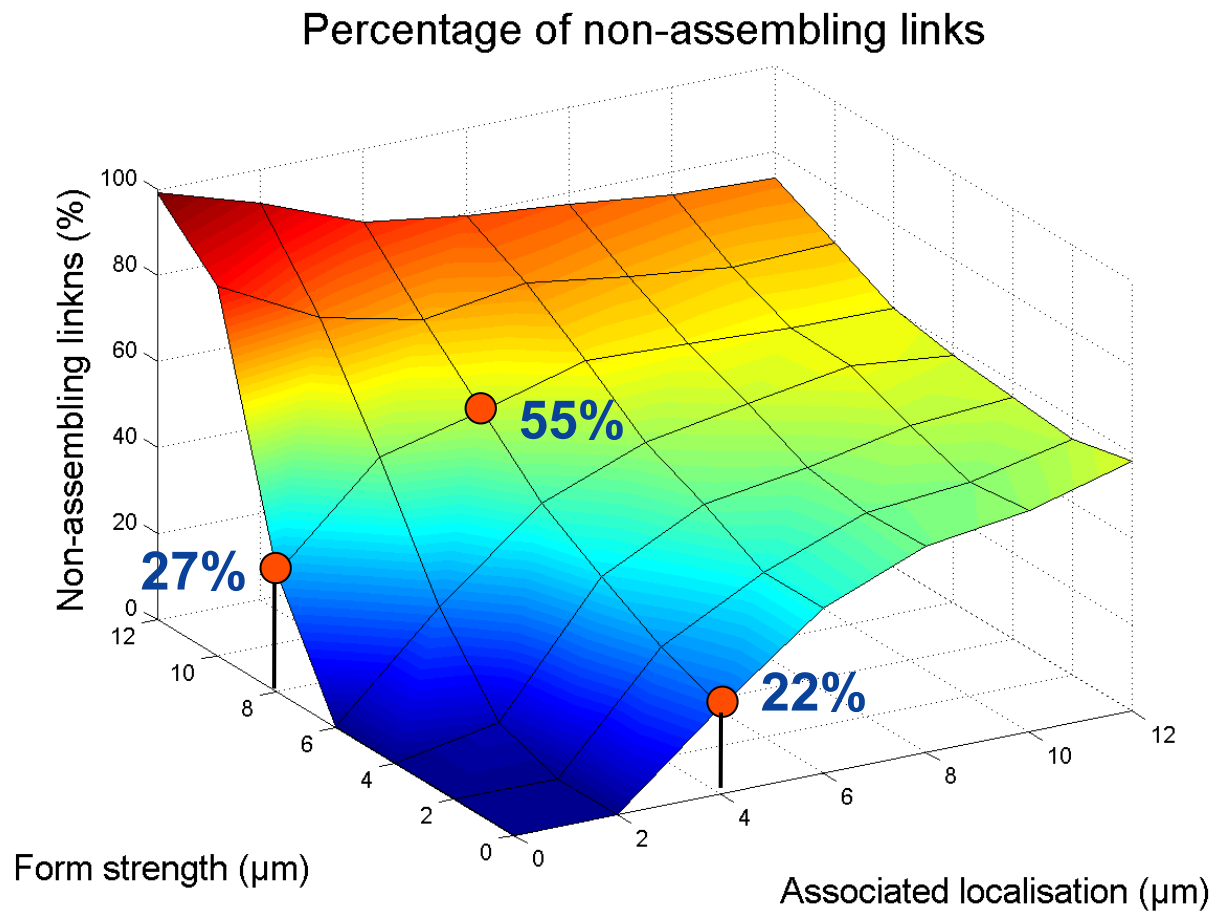
Link clearance domains



Link clearance domains



Assembly rates and GPS criterion



Conclusion

- **The modal parameterization :**
 - describes the shape deviations,
 - filters roughness,
- **The assembling approach:**
 - no undetermined position,
 - no optimization approach,

Prospects

- **To extend on 3D cases with clearance,**
- **Apply to other type of geometry,**
- **Has to be compared to experiments,**

How form errors impact on 2D precision assembly?



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